PB89-214027

Quality Assurance Procedures
Method 28A Measurement of Air to Fuel Ratio and Minimum Burn Rate for Wood-Fired Appliances

Radian Corp., Research Triangle Park, NC

Prepared for:

Environmental Protection Agency, Research Triangle Park, NC

Jul 89

U.S. Department of Commerce
National Technical Information Service
NTIS

PB89-214027

EPA/600/3-89/051
July 1989

QUALITY ASSURANCE PROCEDURES: METHOD 28A MEASUREMENT OF AIR TO FUEL RATIO AND MINIMUM BURN RATE FOR WOOD-FIRED APPLIANCES

by:

R. C. Olin, G. D. Rives, and M. W. Hartman
Radian Corporation
Research Triangle Park, North Carolina 27709

T. E. Ward
Quality Assurance Division
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

68-02-4119

Project Officer:

Thomas E. Ward
Quality Assurance Division
Atmospheric Research and Exposure Assessment Laboratory
Research Triangle Park, North Carolina 27711

Atmospheric Research and Exposure Assessment Laboratory
Office of Research and Development
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/3-89/051	2.	3. RECIPIENT'S ACCESSION NO. PB89 214027/AS
4. TITLE AND SUBTITLE Quality Assurance Procedures: Method 28A Measurement of Air to Fuel Ratio and Minimum Burn Rate for Wood-Fired Appliances		5. REPORT DATE July 1989 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.C. Olin, G.D. Rives, M.W. Hartman, T.E. Ward		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Radian Corporation Research Triangle Park, NC 27709		10. PROGRAM ELEMENT NO. CNMA1E 11. CONTRACT/GRANT NO. 68-02-4119
12. SPONSORING AGENCY NAME AND ADDRESS Atmospheric Research and Exposure Assessment Laboratory Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Quality assurance procedures are contained in this comprehensive document intended to be used as an aid for wood heater manufacturers and testing laboratories in performing measurement of air-to-fuel ratio and minimum burn rate determinations according to EPA protocol, Method 28A. These procedures may be used in research and development, and as an aid in auditing and certification applicability testing. A detailed, step-by-step quality assurance guide is provided to aid in the procurement and assembly of testing apparatus, to clearly describe the procedures, and to facilitate data collection and reporting. Suggested data sheets are supplied that can be used as an aid for both recordkeeping and certification applications. Throughout the document, activity matrices are provided to serve as a summary reference. Checklists are also supplied that can be used by testing personnel. Finally, for the purposes of ensuring data quality, procedures are outlined for apparatus operation, maintenance, and traceability. These procedures combined with the detailed description of the sampling and analysis protocol will help ensure the accuracy and reliability of Method 28A testing results.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 218
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

The information in this document has been funded wholly or in part by the U. S. Environmental Protection Agency under contract number EPA 68-02-4119 to Radian Corporation. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Measurement and monitoring research efforts are designed to anticipate environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina, has responsibility for: assessment of environmental monitoring technology and systems for air, implementation of Agency-wide quality assurance programs for air pollution measurement systems, and supplying technical support to other groups in the Agency including the Office of Air and Radiation, the Office of Toxic Substances, and the Office of Solid Waste.

Emissions from wood heaters are regulated by the Agency, which has published methodology for measurement of these emissions. Proper applications of quality assurance procedures are necessary for production of acceptable data and for determination of the quality of the data produced. This research was undertaken to produce quality assurance procedures for the Agency's Method 28A.

Gary J. Foley
Director
Atmospheric Research and Exposure Assessment Laboratory
Research Triangle Park, North Carolina 27711

ABSTRACT

Quality Assurance Procedures: Method 28A, Measurement of Air to Fuel Ratio and Minimum Burn Rate for Wood-Fired Appliances is a comprehensive document intended to be used as an aid for wood heater manufacturers and testing laboratories in performing measurement of air to fuel ratio and minimum burn rate determinations according to EPA protocol, Method 28A. These procedures may be used in research and development, and as an aid in auditing and certification applicability testing. A detailed, step-by-step quality assurance guide is provided to aid in the procurement and assembly of testing apparatus, to clearly describe the procedures, and to facilitate data collection and reporting. Suggested data sheets are supplied that can be used as an aid for both recordkeeping and certification applications. Throughout the document, activity matrices are provided to serve as a summary reference. Checklists are also supplied that can be used by testing personnel. Finally, for the purposes of ensuring data quality, procedures are outlined for apparatus operation, maintenance, and traceability. These procedures combined with the detailed description of the sampling and analysis protocol will help ensure the accuracy and reliability of Method 28A testing results.

CONTENTS

Foreword iii
Abstract iv
Tables xi
Figures xii
Introduction xv
Conclusions xv
Recommendations xv

Summary of Method 28A xvi
Method Highlights xvii
Quality Assurance Procedures Highlights xvii

1.0 Procurement of Apparatus and Supplies 1-1

1.1 Apparatus and Supplies for Installation of Wood Heater Flue Pipe 1-3

1.1.1 Wood Heater Steel Flue Pipe 1-3
1.1.2 Insulated Solid Pack Chimney 1-3
1.1.3 Liquid Seal (Optional) 1-5
1.1.4 Flue Damper 1-7
1.1.5 Miscellaneous Equipment for Installation of Wood Heater and Flue Pipe 1-7

1.2 Apparatus and Supplies for Process Measurements 1-7

1.2.1 Platform Scale 1-7
1.2.2 Draft Gauge 1-10
1.2.3 Miscellaneous Equipment for Process Measurements 1-10

1.3 Apparatus and Supplies for Measuring Test Facility Conditions 1-10

1.3.1 Temperature Monitoring Device 1-10
1.3.2 Anemometer 1-12
1.3.3 Humidity Gauge 1-12
1.3.4 Barometer 1-12

1.4 Apparatus and Supplies for Measuring Test Fuel Parameters 1-13

1.4.1 Apparatus and Supplies for Measuring Firebox Volume 1-13
1.4.2 Test Fuel Supplies for Wood Heater Operation 1-13
1.4.3 Apparatus for Test Fuel Storage 1-13

CONTENTS (Continued)

1.4.4 Moisture Meter 1-14
1.4.5 Test Fuel Balance (Optional) 1-16
1.4.6 Fuel Temperature Monitor 1-16
1.4.7 Apparatus and Supplies for Test Fuel Crib Construction 1-16

1.5 Apparatus and Supplies for Sampling and Analysis 1-17

1.5.1 Integrated Gas Sampling (for Orsat Analyzer) 1-17
1.5.2 Continuous Emission Monitoring System (CEMS) . 1-25

2.0 Calibration of Apparatus 2-1

2.1 Platform Scale and Monitor 2-1

2.1.1 Frequency and Specifications of Calibration .. 2-1
2.1.2 Method of Calibration 2-1

2.2 Test Fuel Balance (Optional) 2-3

2.2.1 Frequency and Specifications of Calibration .. 2-3
2.2.2 Method of Calibration 2-3

2.3 Facility Temperature Monitor 2-3

2.3.1 Frequency and Specifications of Calibration .. 2-3
2.3.2 Calibration Procedures 2-5

2.4 Anemometer 2-5

2.4.1 Frequency and Specifications of Calibration .. 2-5
2.4.2 Method of Calibration 2-5

2.5 Barometer 2-7

2.5.1 Frequency and Specifications of Calibration .. 2-7
2.5.2 Method of Calibration 2-7

2.6 Draft Gauge 2-9

2.6.1 Frequency and Specifications of Calibration .. 2-9
2.6.2 Method of Calibration 2-9

2.7 Humidity Gauge 2-9

2.7.1 Frequency and Specifications of Calibration .. 2-9
2.7.2 Method of Calibration 2-9

CONTENTS (Continued)

2.8 Wood Moisture Meter 2-9

2.8.1 Frequency and Specifications of Calibration .. 2-9
2.8.2 Method of Calibration 2-10
2.8.3 Oven-Drying Method 2-10

2.9 Orsat Analyzer 2-12

2.9.1 Frequency and Specifications of Calibration .. 2-12
2.9.2 Method of Calibration 2-12

2.10 Rotameter 2-14

2.10.1 Frequency and Specifications of Calibration 2-14
2.10.2 Method of Calibration 2-14

2.11 Instrumental Analyzers 2-16

2.11.1 Frequency and Specifications of Calibration 2-16
2.11.2 Method of Calibration 2-18

3.0 Pretest Procedures 3-1

3.1 Process Operation Pretest Procedures 3-1

3.1.1 Measurement of Usable Firebox Volume 3-1
3.1.2 Wood Heater Installation 3-7
3.1.3 Liquid Seal and Adapter Sections 3-12
3.1.4 Apparatus Check and Calibration 3-12
3.1.5 Test Fuel Measurements 3-13
3.1.6 Test Fuel Crib Construction 3-17
3.1.7 Pretest Facility Condition Measurement 3-21
3.1.8 Pretest Burn Conditions 3-23

3.2 Orsat Sampling and Analysis Pretest Procedures 3-26

3.2.1 Equipment Installation 3-26
3.2.2 Equipment Check 3-27

3.3 CEMS Pretest Procedures 3-28

3.3.1 Checking the Apparatus 3-28
3.3.2 Installation and Calibration 3-30

3.4 Summary of Pretest Procedures 3-31

CONTENTS (Continued)

4.0 Test Run Procedures 4-1

- 4.1 Starting the Test Run 4-1
  - 4.1.1 Requirements for Starting the Test Run 4-1
  - 4.1.2 Final Pretest Measurements 4-2
  - 4.1.3 Gas Sampling 4-2
  - 4.1.4 Test Fuel Loading 4-4
- 4.2 Data Recording 4-4
- 4.3 Adjustments During the Test Run 4-5
  - 4.3.1 Wood Heater Adjustments 4-5
  - 4.3.2 Test Fuel Adjustment 4-5
  - 4.3.3 Sample Flow Adjustments 4-6
  - 4.3.4 Sample System Adjustments 4-6
- 4.4 Completion of the Test Run 4-6

5.0 Post-Test Procedures 5-1

- 5.1 Facility and Process Measurements 5-1
  - 5.1.1 Test Facility Condition Measurements 5-1
  - 5.1.2 Post-Test Acceptance Checks 5-1
- 5.2 Equipment Leak Checks and Calibrations 5-1
  - 5.2.1 Orsat Analyzer Method 5-1
  - 5.2.2 CEMS 5-2
- 5.3 Data Retrieval 5-2
  - 5.3.1 Orsat Method 5-2
  - 5.3.2 CEMS 5-5
- 5.4 Data Validation Procedures 5-6
  - 5.4.1 Orsat Analyzer Method 5-6
  - 5.4.2 CEMS 5-6

6.0 Calculations 6-1

- 6.1 Dry Burn Rate 6-1
- 6.2 Sample Gas Concentrations 6-2

CONTENTS (Continued)

6.2.1 Orsat Analyzer 6-2
6.2.2 CEMS 6-2

6.3 Air to Fuel Ratio 6-3

6.4 CEMS Data Verification Calculations 6-4

7.0 Maintenance 7-1

7.1 Platform Scale 7-1

7.2 Test Fuel Scale or Balance 7-1

7.3 Moisture Meter 7-1

7.4 Anemometer 7-2

7.5 Manometer 7-2

7.6 Pumps 7-2

7.7 Rotameter 7-2

7.8 Orsat Analyzer 7-3

7.9 Instrumental Analyzers 7-3

7.10 Other Sampling Train Components 7-3

8.0 Auditing Procedures 8-1

8.1 Performance Audits 8-1

8.1.1 Audit of Analytical Phase Using Certified Gas Mixtures 8-1
8.1.2 Audit of Process Measurement Equipment and Procedures 8-3
8.1.3 Data Processing 8-4

8.2 Systems Audit 8-4

9.0 Recommended Standards for Establishing Traceability 9-1

9.1 Traceability Protocol for Establishing True Concentration of Gases Used for Calibration and Audit 9-1

CONTENTS (Continued)

9.2 Establishing Traceability of Commercial Cylinder Gases to NBS-SRM Cylinder Gases 9-2

 9.2.1 Multipoint Calibration 9-2
 9.2.2 Instrument Span Check for Linear Responses ... 9-3
 9.2.3 Instrument Span Check for Nonlinear Response 9-3

9.3 Determining True Concentrations of Cylinder Gases ... 9-4

9.4 Using Gas Manufacturer's Primary Standards 9-5

9.5 Verifying Cylinder Gas Stability 9-5

9.6 Reanalyzing Cylinder Gases 9-5

9.7 Minimum Cylinder Pressure 9-6

9.8 Labeling the Cylinder and Preparing the Analysis Report 9-6

9.9 Conducting Performance Audits 9-7

10.0 Reference Method 10-1

11.0 References 11-1

12.0 Data Sheets 12-1

TABLES

Table | Page

1.1 Examples of Platform Scales with Capacity and Resolution 1-9

1.2 Activity Matrix: Procurement of Apparatus and Supplies .. 1-34

2.1 Activity Matrix: Calibration of Apparatus 2-26

3.1 Activity Matrix for Pretest Procedures 3-37

4.1 Activity Matrix for Test Run Procedures 4-7

5.1 Activity Matrix for Post-Sampling Operations 5-7

7.1 Activity Matrix: Equipment Maintenance Checks 7-4

8.1 Activity Matrix for Auditing Procedures 8-7

FIGURES

Figure Page

1.1 Procurement Log 1-2
1.2 Wood Heater and Flue Installation 1-4
1.3 Liquid Seal 1-6
1.4 Facility Temperature Monitoring Apparatus 1-11
1.5 Equilibrium Moisture Content 1-15
1.6 Integrated Gas Sampling Train 1-18
1.7 Example Rotameter Calibration Curve 1-20
1.8 Plastic Bag Leak Check System 1-22
1.9 Orsat Apparatus 1-24
1.10 Example CEMS Installation 1-27
2.1 Scale Calibration Record Sheet 2-4
2.2 Temperature Monitor Calibration Record Sheet 2-6
2.3 Semiannual Calibration Record Sheet 2-8
2.4 Moisture Meter Calibration Sheet 2-11
2.5 $\bar{X}$ and R Chart 2-13
2.6 Rotameter Calibration Data Sheet 2-15
2.7 Rotameter Calibration Curve 2-17
2.8 Example Calibration Setup 2-20
2.9 Sample Calibration Curve 2-22
2.10 Calibration Drift Verification Record Chart 2-25
3.1 Example of Usable Firebox Volume 3-4
3.2 Example of Scale Firebox Drawings to Document Usable Volume Determinations 3-5

FIGURES (Continued)

Figure Page

3.3 Example of Firebox Volume Divided Into Specific Component Volumes 3-6

3.4 Example Calculation of Specific Firebox Volume (Based on Components Illustrated in Figure 3.3) 3-8

3.5 Documentation of Test Fuel Measurements 3-15

3.6 Dimensions of Test Fuel Pieces and Spacers 3-19

3.7 Test Fuel Crib Arrangements 3-20

3.8 Measurement of Test Facility Conditions 3-22

3.9 Summary of Adjustments and Activities During Pretest Burn Procedures 3-24

3.10 Typical Continuous Emission Monitoring System (CEMS) Sampling Apparatus 3-29

3.11 Checklist for Method 28A Pretest Procedures 3-32

4.1 Test Measurements Recording Sheet 4-3

5.1 Orsat Analyzer Gas Analysis Sheet 5-4

8.1 Checklist to be Used by Auditors 8-6

12.1 Sheet 28A-1.1 - Procurement Log 12-2

12.2 Sheet 28A-1.7 - Example Rotameter Calibration Curve 12-3

12.3 Sheet 28A-2.1 - Scale Calibration Record Sheet 12-4

12.4 Sheet 28A-2.2 - Temperature Monitor Calibration Record Sheet 12-5

12.5 Sheet 28A-2.3 - Semiannual Calibration Record Sheet 12-6

12.6 Sheet 28A-2.4 - Moisture Meter Calibration Sheet 12-7

12.7 Sheet 28A-2.5 - $\bar{X}$ and R Chart 12-8

12.8 Sheet 28A-2.6 - Rotameter Calibration Sheet 12-9

FIGURES (Continued)

Figure		Page
12.9	Sheet 28A-2.7 - Rotameter Calibration Curve	12-10
12.10	Sheet 28A-2.9 - Sample Calibration Curve	12-11
12.11	Sheet 28A-2.10 - Calibration Drift Verification Record Chart	12-12
12.12	Sheet 28A-3.5 - Documentation of Test Fuel Measurements	12-13
12.13	Sheet 28A-3.8 - Measurement of Test Facility Conditions	12-15
12.14	Sheet 28A-3.9 - Summary of Adjustments and Activities During Pretest Burn Procedures	12-16
12.15	Sheet 28A-3.11 - Checklist for Method 28A Pretest Procedures	12-17
12.16	Sheet 28A-4.1 - Test Measurements Recording Sheet	12-22
12.17	Sheet 28A-5.1 - Orsat Analyzer Gas Analysis Sheet	12-23
12.18	Sheet 28A-8.1 - Checklist to be Used by Auditors	12-24

INTRODUCTION

Quality Assurance Procedures: Method 28A, Measurement of Air to Fuel Ratio and Minimum Burn Rate for Wood-Fired Appliances has been prepared as an aid for wood heater manufacturers and testing laboratories in performing wood heater procedures specified in Method 28A and in ensuring data quality and reliability. This manual may be used in combination with Method 28A for designing an individualized quality assurance program.

CONCLUSIONS

It is concluded that these procedures will be helpful in ensuring and establishing the quality of the data when sampling according to the requirements of Method 28A. This will be beneficial for data producing activities including research and development, and as an aid for certification applicability determination.

RECOMMENDATIONS

These quality assurance procedures may be used in the individualized quality assurance program established by each user. Copies of the checklists and summary activity matrices provided herein may be supplied to testing personnel to ensure that the desired quality assurance procedures are followed. Also, copies of blank data sheets can aid the user in ensuring and establishing data quality in sampling applicability data.

SUMMARY OF METHOD 28A

Method 28A specifies the procedures for measurement of air-to-fuel ratio and minimum burn rates for wood-fired appliances. Method 28A is in Appendix A, 40 CFR 60. For reference purposes only a complete copy of Method 28A, Appendix A, 40 CFR 60 (53 FR 5911) is included in Section 10.0 of these procedures. Wood heaters with documented average air-to-fuel ratios of 35 to 1 or greater, or with minimum burn rates of 5 kg/h or more, are not covered under the wood heater New Source Performance Standard (NSPS) (40 CFR 60.530 et seq.). Thus, a Method 28A test run is a certification applicability determination. The standard requires that this determination be made by an EPA-accredited testing laboratory.

Method 28A prescribes the firebox volume determination procedures, fuel weight and arrangement, wood heater adjustments, test facility conditions, and wood heater operation during air-to-fuel ratio determination testing. Many of these procedures are the same as those specified in EPA Method 28, "Certification and Auditing of Wood Heaters."

The minimum burn rate determination includes guidelines for modifying and adjusting air and exhaust flow restriction devices. The requirements for measuring fuel weight and determining burn duration are described as in Method 28.

The air-to-fuel ratio determination involves sampling exhaust gases from the flue of wood-fired appliances and analyzing for percent carbon dioxide (CO_2), percent oxygen (O_2), and percent carbon monoxide (CO). The concentrations of these stack gas constituents are used, along with the quantity of fuel consumed and the test burn duration, to determine the air-to-fuel ratio.

Method 28A describes two sampling and analysis options. The first option is an integrated bag sampling approach in which stack gases are collected in leak-free, inert, flexible bags. The sampling is performed at a constant rate and continues for the duration of the burn cycle. The second approach for determining air-to-fuel ratios is by a continuous emission monitoring system (CEMS) in which stack gases are sampled and analyzed for CO, CO_2, and O_2 with instrumental analyzers.

METHOD HIGHLIGHTS

EPA Method 28A contains all the requirements and describes the apparatus and procedures for measuring minimum burn rate and air-to-fuel ratio for wood heaters. The apparatus and procedures used are similar to those used for Method 28, "Certification and Auditing of Wood Heaters." Method 28A is unique in that its purpose is to determine whether further particulate emissions testing is required. Thus, Method 28A focuses on wood heater process characteristics rather than emissions. However, stack gas analysis (for CO_2, O_2, and CO) is used to calculate process parameters (i.e., air-to-fuel ratios). To get accurate and repeatable results, it is extremely important to follow the procedures described in Method 28A closely. Following the test procedures closely is ultimately to the advantage of both the wood heater manufacturer and the test laboratory.

QUALITY ASSURANCE PROCEDURES HIGHLIGHTS

The purpose of these procedures, Quality Assurance Procedures: Method 28A, Measurement of Air to Fuel Ratio and Minimum Burn Rate for Wood-Fired Appliances is to be used as an aid in assembling the testing apparatus, to list and describe the required procedures, and to facilitate the data recording. Activity matrices are provided at the end of the appropriate sections. Section 12.0 contains blank data sheets which can be reproduced and used as an aid in data collection and recording. Examples of the use of these sheets are given in the appropriate sections of this Manual.

1. Procurement of Equipment

Section 1.0 presents the specifications, criteria, and design features for the equipment and materials that are required to set up and operate a wood heater according to Method 28A. This section is intended to inform the user of the apparatus selection options and the rationale for selecting a particular piece of equipment or analytical method. The activity matrix given at the end of Section 1.0 can be used as a convenient checklist for equipment procurement and initial acceptance check procedures.

2. Calibration

Section 2.0 provides an item-by-item, step-by-step guide to the required calibration procedures and frequencies. Some of the apparatus (e.g., platform scale, moisture content meter, and instrumental analyzers) require calibration before each test run, while other pieces of apparatus require calibration semiannually.

An activity matrix is provided at the end of Section 2.0 as a summary of the calibration procedures.

3. Pretest Procedures

Section 3.0 describes procedures that are conducted before gas sampling begins. These procedures include firebox volume measurements, wood heater installation, apparatus check and calibration, test fuel measurements and crib construction, measurement of the facility conditions, and presampling burn activities. Illustrations, examples, and an activity checklist are provided to assist testing personnel in performing and documenting pretest procedures. An activity matrix provides a summary of the purpose, specifications, and time and frequency of each pretest activity.

4. Test Run Procedures

Section 4.0 lists and describes the activities performed during the test run. These activities include beginning the test run, measurement of test run data at 10-min intervals, adjustment of fuel and air supply settings, test run completion, and recording of data. An activity matrix is provided listing in chronological order each activity performed during the test run.

Illustrations and examples are provided to assist testing personnel in performing and documenting test run activities.

5. Post-Test Procedures

Section 5.0 describes the activities required at the end of the certification test. These include: the measurement of test facility condition parameters, sampling train and equipment leak checks, and either determination of gas concentration using an Orsat analyzer or data verification by span and zero drift determination for CEMS. Recommended procedures also include performing a calibration check on the platform scale and measurement of the fluid level in the liquid seal.

6. Calculations

Section 6.0 describes calculations necessary for interpreting the data obtained. Calculations for determining dry burn rate and air-to-fuel ratio are provided. Also, calculations required to determine F_0, a fuel factor data quality indicator, are described. Examples are included.

7. Maintenance

Section 7.0 summarizes recommendations on maintenance of equipment.

8. Auditing Procedures

Section 8.0 describes recommended audit procedures, including both performance audits and system audits. A table is provided that summarizes these procedures.

9. Recommended Standards for Establishing Traceability

Section 9.0 recommends the primary standards to which the wood heater operation and sample analysis measurements are traceable.

10. Reference Method

Section 10.0 contains a copy of Method 28A as published in the Federal Register (40 CFR 60.530). Copies of Methods 28 and 5H are also included since these are often referenced in Method 28A.

11. References

Section 11.0 provides the reader with a list of the references used in the preparation of this Manual.

12. Data Sheets

Section 12.0 provides sheets that can be used for calculations, record keeping, and data reporting. These sheets may be removed and duplicated.

1.0 PROCUREMENT OF APPARATUS AND SUPPLIES

As discussed in the summary section of this document, Method 28A lists specifications for wood heater installation and prescribes limits on test facility conditions, fuel properties, and wood heater operating conditions during minimum burn rate and air-to-fuel ratio determination testing.* This section lists and describes the apparatus and supplies necessary to perform wood heater emission tests according to Method 28A. Applicable specifications, criteria, and/or design features are given to aid in the selection of equipment that will help ensure accurate results. Procedures and limits (where applicable) for equipment acceptance checks are also given.

During the procurement of equipment and supplies, a procurement log (Figure 1.1) should be used to record a description of the equipment, the identification number (if applicable), and the results of acceptance checks. If calibration is required as part of the acceptance check, the calibration data should also be recorded in a calibration log. Table 1.2, at the end of this section, is a summary of the quality assurance activities for the procurement and acceptance of apparatus and supplies.

Discussion of the procurement of apparatus and supplies is organized into five subsections. These are as follows:

1. Apparatus and Supplies for Installation of Wood Heater and Flue Pipe;
2. Apparatus and Supplies for Process Measurements;
3. Apparatus and Supplies for Measuring Test Facility Conditions;
4. Apparatus and Supplies for Determining Test Fuel Parameters; and
5. Apparatus and Supplies for Sampling and Analysis.

---

*Method 28A, Appendix A, 40 CFR 60 contains the complete requirements for Method 28A test procedures. The quality assurance procedures in this document may be used as an aid in ensuring data quality and reliability.

Item Description	Quantity	Purchase Order Number	Vendor	Date Ordered	Date Received	Cost	Disposition	Comments
Moisture Meter	1	250	ABC	4/1/88	4/15/88	300	in use	OK

Figure 1.1. Procurement Log

1.1 Apparatus and Supplies for Installation of Wood Heater Flue Pipe

Figure 1.2 is an example wood heater and flue pipe installation configuration that conforms to the requirements of Method 28A. This figure shows both required and recommended equipment. The wood heater and flue pipe assembly shown in Figure 1.2 or a similar configuration can also be used for Method 28, Certification Testing of Wood Heaters, with either of the emission sampling methods (i.e., Methods 5H or 5G). The components shown in Figure 1.2 are discussed in the following subsections.

1.1.1 Wood Heater Steel Flue Pipe - The steel flue pipe must extend to a height of 2.6 ± 0.15 m (8.5 ± 0.5 ft) above the scale platform. This distance should be measured from the platform on which the wood heater sits. A standard stove pipe (i.e., black wall - 24 gauge) is recommended. The steel flue pipe must be of a diameter specified by the wood heater manufacturer, usually standard 6- or 8-in. pipe. Other than single-wall steel flue pipe is allowed if specified by the manufacturer.

The flue pipe sections must fit tightly to ensure secure assembly, as well as unbiased draft gauge measurements. For joints between the upper steel flue pipe section and the insulated solid pack section, high-temperature sealant and sheet metal screws are recommended for all connections.

Because wood heater heights and exhaust flange diameters may vary, an assortment of adapter sections may be necessary. Further, since some wood heater flanges may require that the adapter section be sealed with furnace cement or other sealant, the adapter sections will not always be reusable. It is recommended that the draft gauge port, which must be within 0.3 m (1 ft) of the wood heater exhaust flange, be located in the adapter section.

1.1.2 Insulated Solid Pack Chimney - Insulated solid pack (ISP) chimney is a special flue pipe designed specifically for going through ceilings or roofs. It should have the same inside diameter as the steel flue pipe. The purpose of the ISP is to duplicate real-world induced draft conditions. The ISP section must extend from the steel flue pipe section to a height of

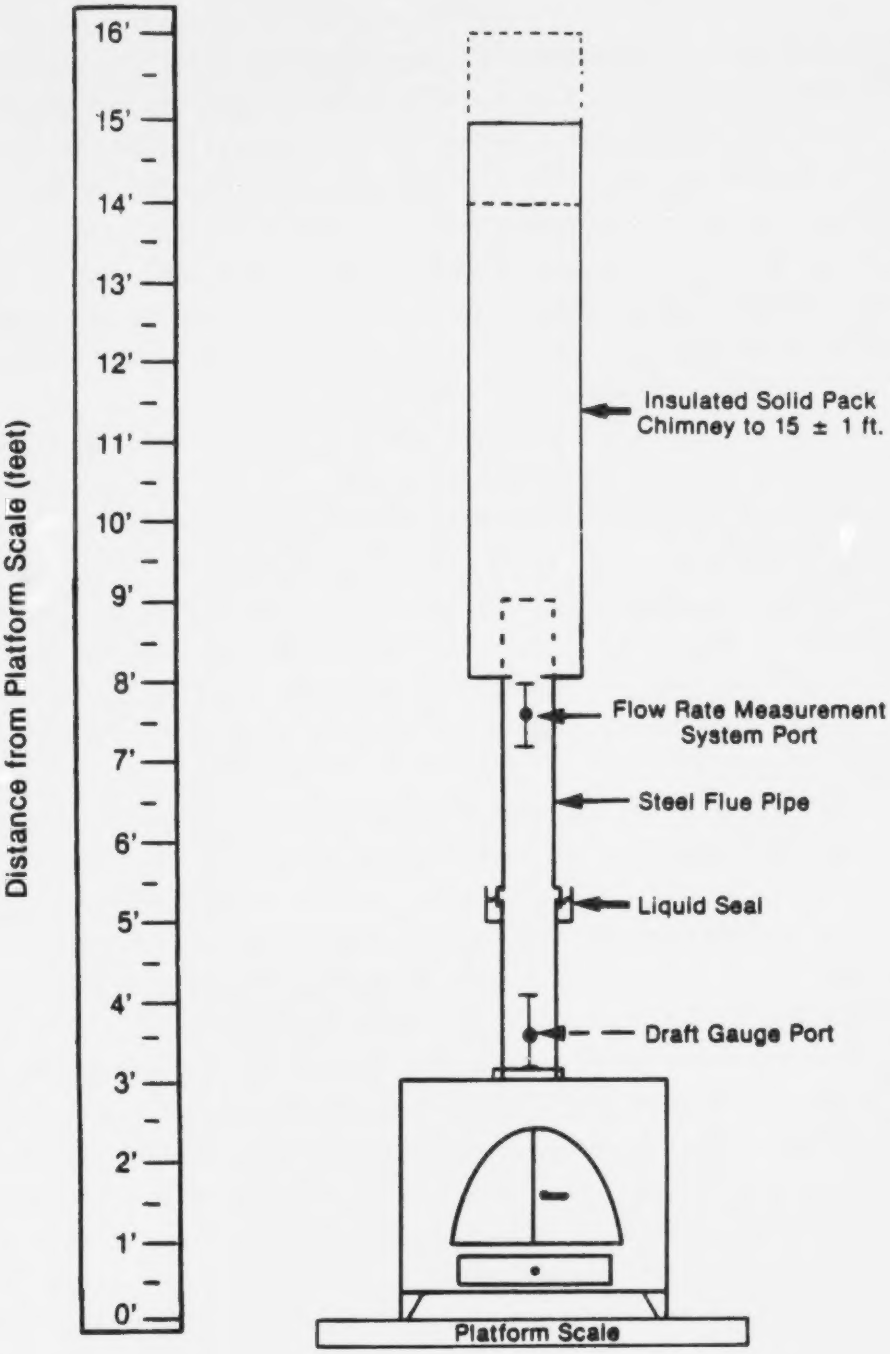

16'
15'
14'
13'
12'
11'
10'
9'
8'
7'
6'
5'
4'
3'
2'
1'
0'
Distance from Platform Scale (feet)
Insulated Solid Pack Chimney to 15 ± 1 ft.
Flow Rate Measurement System Port
Steel Flue Pipe
Liquid Seal
Draft Gauge Port
Platform Scale

Figure 1.2. Wood Heater and Flue Installation

4.8 ± 0.3 m (15 ± 1 ft) above the platform scale. Thus, the ISP section length could range from 1.5 to 2.4 m (5 to 8 ft) depending on the height of the steel flue pipe section. Method 28A also requires that the insulation material be no more than 2.5 cm (1 in.) thick and that the ISP meet the temperature and strength requirements of Underwriters Laboratories (UL) specification UL 103. Any solid pack chimney tested and listed according to the UL standard is acceptable. Testing and listing may be performed by companies other than UL. Several commercially available ISPs such as "Insulpak" and "Metalbestos" meet these requirements.

Because an ISP typically weighs about 15 kg per linear meter (10 lb per linear foot), it should be firmly supported. The ISP manufacturer's recommendations should be followed to attach supports to the ISP.

1.1.3 Liquid Seal (Optional) - If the ISP section is firmly supported as recommended in Subsection 1.1.2, a device will be required that will allow both unobstructed vertical movement of the scale platform and an airtight seal. A liquid seal (see Figures 1.2 and 1.3) is a device that serves this purpose.

A liquid seal is recommended because the alternative of a freestanding steel pipe-ISP assembly could pose a safety problem if it is not firmly supported, particularly on smaller wood heaters. The liquid seal allows free scale movement and thus accurate readings with the ISP firmly supported. Also, a liquid seal puts less weight on the platform scale than does the ISP section, thus allowing a lower capacity scale.

Figure 1.3 shows an example design that can be fabricated from sheet metal. The liquid seal should be no more than 0.6 m (2 ft) from the wood heater exhaust flange to minimize the scale-supported weight, to facilitate liquid level inspection, and to minimize interference with stack sampling. A liquid seal depth (i.e., liquid capacity) of about 15 cm (6 in.) allows sufficient clearance for installation.

The liquid seal should be filled with an oil demonstrating a high boiling point and a low vapor pressure. Before installation, the seal should be checked for leakage. As a further check, the liquid level should be monitored during and after each test run. A leaking liquid seal would affect the burn rate and end-of-test determinations.

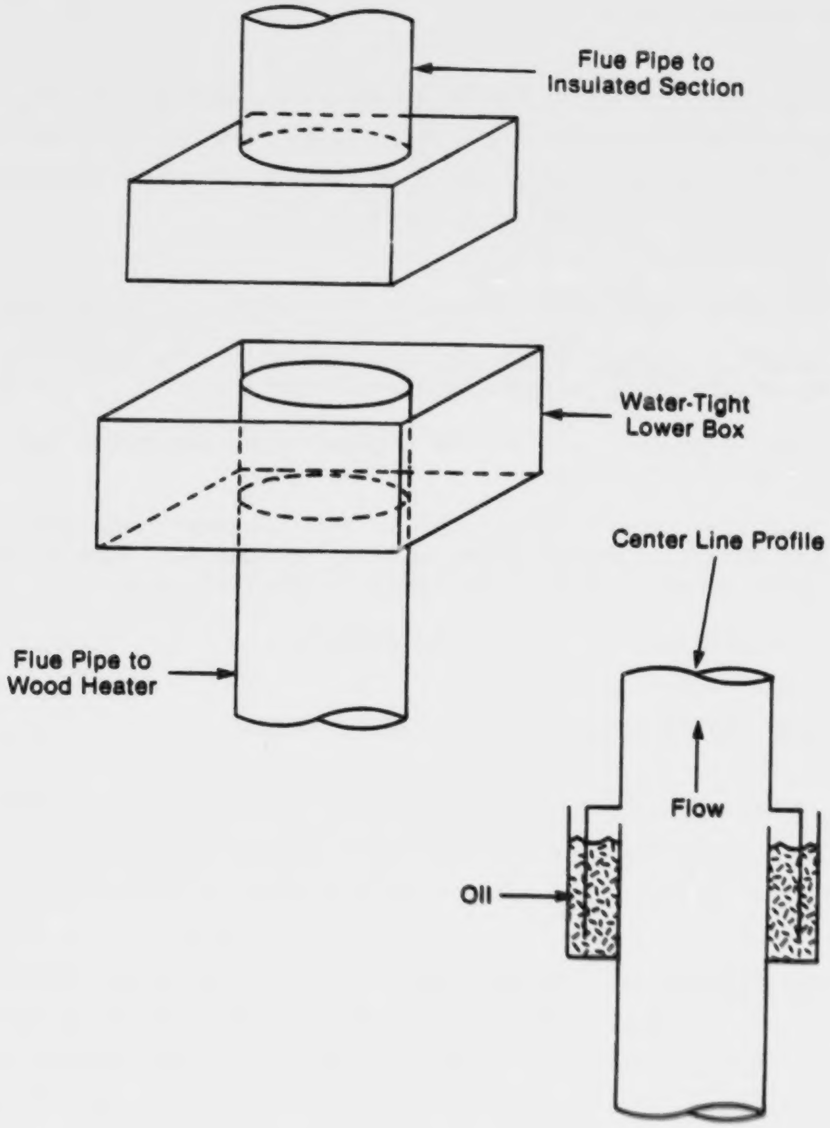

Flue Pipe to Insulated Section
Water-Tight Lower Box
Center Line Profile
Flue Pipe to Wood Heater
Flow
Oil

Figure 1.3. Liquid Seal

1.1.4 Flue Damper - Method 28A requires that a commercially available flue damper be installed in some circumstances (see Section 3.1.8.2). The damper should be installed below the liquid seal and within 0.3 m (1 ft) of the wood heater exhaust flange.

1.1.5 Miscellaneous Equipment for Installation of Wood Heater and Flue Pipe - This section lists miscellaneous equipment and supplies for wood heater and flue pipe installation not specifically listed in the preceding subsection headings. This equipment includes:

- Oil (for liquid seal, if used); a synthetic oil is recommended;
- Brackets, clamps, fasteners, or other devices as specified by the manufacturer for supporting the ISP section;
- High temperature sealant for sealing pipe connections and sampling or measurement ports;
- Hand tools and fasteners such as drill, hammer, wood saw, hacksaw, tin snips, stovepipe crimping tool, screwdriver, wrench, sheet metal screws, and nuts and bolts as required; and
- Flue pipe adapter sections as needed.

1.2 Apparatus and Supplies for Process Measurements

Process measurements during a wood heater certification applicability test include burn rate and flue draft. Apparatus and supplies required for performing these process measurements are discussed in this subsection.

1.2.1 Platform Scale - Method 28A requires that the platform scale have a resolution (i.e., readout graduations) of 0.05 kg (0.1 lb) or 1% of the test load weight, whichever is greater (see Section 3.1.6.2 for determination of test load weight). The scale must also have a capacity sufficient to support the heaviest anticipated wood heater (plus test load and flue pipe assembly). It is recommended that the scale have a "tare" feature. The tare feature is an "automatic zero."

When choosing a suitable platform scale, there are several factors to consider: ease of calibration, required capacity, resolution, and temperature sensitivity. The scale manufacturer's recommended calibration procedures should be compared with the requirements listed in Section 2.1 of this manual. For example, some scales provide for a span adjustment with the tare weight set (i.e., the wood heater in place). Other scales may require that the scale be calibrated without the wood heater in place. Another important consideration in calibration is the scale's sensitivity to temperature variations. Some scales have a specified operating temperature range. These scales may require heat insulation beneath the wood heater to prevent electrical component damage and to ensure consistent calibration. Since the scale calibration should be checked at testing temperatures (e.g., during the pre-burn test), a span adjustment with the tare weight set is a highly desirable feature.

The required resolution of the platform scale is dictated by the test load weight, which is determined by the size of the wood heater firebox. The finest resolution that will ever be required is 0.05 kg (0.1 lb). A platform scale with a resolution greater than 0.05 kg (0.1 lb) is acceptable for large fireboxes. For example, a wood heater with a firebox volume less than 2.2 ft^3 would require a platform scale with a resolution of 0.1 lb (i.e., 1% of the test fuel load: 0.1 lb = 1% x 2.2 ft^3 x 7 lb/ft^3). In general, a scale with a resolution of 0.05 kg (0.1 lb) is recommended because it will accommodate a full range of wood heaters.

A wide variety of scale capacities and resolutions is available commercially. As examples, some platform scales with their capacities and resolutions are listed in Table 1.1. Although wood heaters up to 800 kg (1760 lb) may require testing, most wood heaters to be tested will weigh less than 454 kg (1000 lb). Note: If a platform scale with a resolution of 0.1 kg (0.2 lb) is used, another balance with a resolution of 0.05 kg (0.1 lb) or less must be used to measure the test load weight.

TABLE 1.1 EXAMPLES OF PLATFORM SCALES WITH CAPACITY AND RESOLUTION

Manufacturer[a]	Capacity	Resolution
Arlyn Scales	500 lb	0.1 lb
Arlyn Scales	1000 lb	0.2 lb
Circuits and Systems	500 lb	0.1 lb
Circuits and Systems	1000 lb	0.2 lb
Malvern Scale	600 lb	0.01 lb
Toledo Scales	1000 lb	0.1 lb
General Electronics Systems	1000 lb	0.1 lb

[a] These manufacturers are listed in the 1985 Thomas Register of American Manufacturers.

1.2.2 Draft Gauge - The reference method requires a draft gauge to measure the draft induced at the wood heater exhaust flange. The draft gauge must be able to measure negative pressure in the flue pipe at 1.25 Pa (0.005 in. H_2O). The resolution should be 0.5 Pa (0.002 in. H_2O) or less.

Micromanometers, instruments for measuring small variations in pressure, can be electronic or liquid (e.g., U-type). Liquid manometers do not require calibration. Both electronic and liquid micromanometers can meet the required specifications.

1.2.3 Miscellaneous Equipment for Process Measurements - This section describes recommended and required equipment and supplies not listed in the preceding subsection headings.

- Calibration weights: One Class F standard weighting from 20 to 80% of the anticipated test load weight is required to check scale calibration. Five Class F weights over the span of the scale range may be required for 5-point calibration (see Section 2.1).
- A heat insulating pad to ensure that the platform scale is maintained within the temperature range specified by the manufacturer (see Figure 1.4).

1.3 Apparatus and Supplies for Measuring Test Facility Conditions

Method 28A requires that test facility conditions be measured and recorded before and after each certification test. This section lists and describes the necessary equipment.

1.3.1 Temperature Monitoring Device - Method 28A requires a temperature monitoring device with an accuracy of $\pm1.5\%$ of the absolute temperature. This corresponds to about $\pm4^{\circ}C$ ($8^{\circ}F$) at test facility temperatures. The temperature detecting section must be at the center of a cylindrical shield 150 mm (6 in.) long and 50 mm (2 in.) in diameter.

A mercury-in-glass thermometer with its bulb at the center of the cylindrical shield is suitable for this purpose. An alternative is to use a

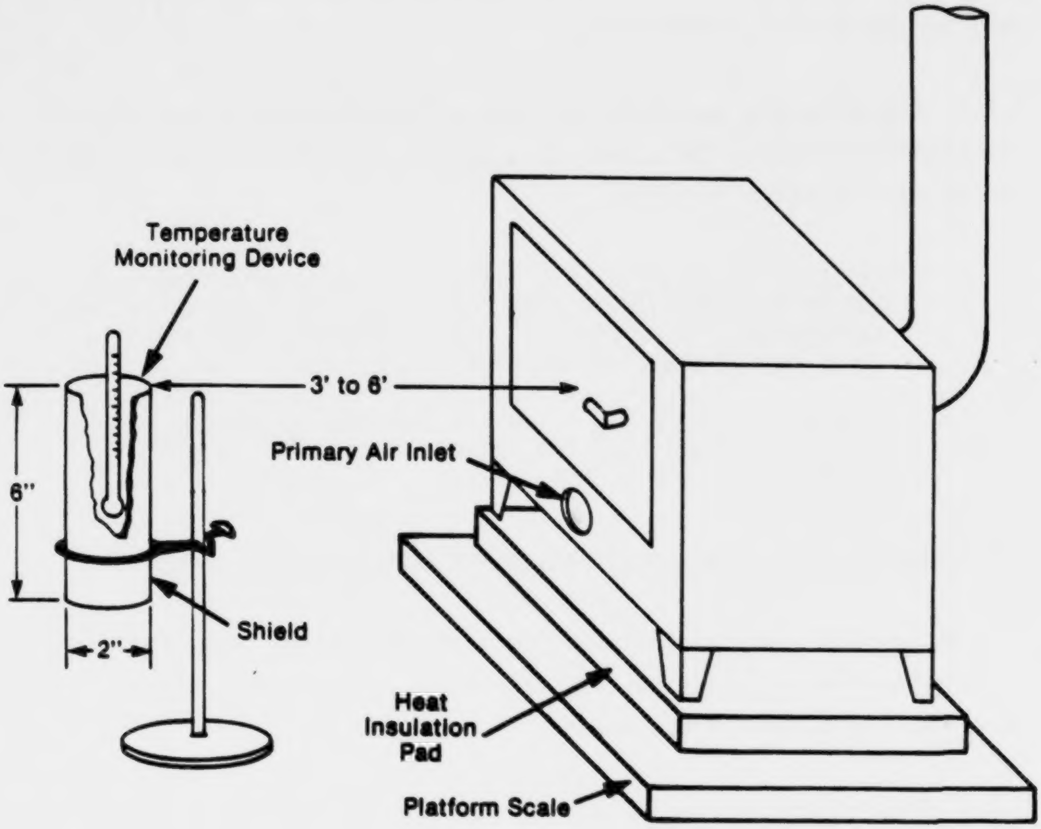

Temperature Monitoring Device
3' to 6'
6"
2"
Shield
Primary Air Inlet
Heat Insulation Pad
Platform Scale

Figure 1.4. Facility Temperature Monitoring Apparatus

thermocouple with a readout device. A thermocouple similar to those used in Method 28 for measuring wood heater surface temperatures can be used.

The cylindrical shield can be fabricated to the required dimensions from sheet metal or other suitable material. The cylinder should be of a reflective color (e.g., silver) to minimize radiant heat effects. Figure 1.4 is an example of a suitable facility temperature monitoring device.

1.3.2 Anemometer - Method 28A requires an anemometer to ensure that air velocity in the vicinity of the wood heater is less than 0.25 m/s (50 ft/min). The anemometer should be able to measure air velocities as low as 0.1 m/s (20 ft/min).

Two types of instruments are capable of meeting these specifications: electronic anemometers (hot wire type) and vane anemometers. Electronic anemometers are available that can measure in the range from 0 to 1.5 m/s (300 ft/min) with accuracies of ±0.03 m/s (6 ft/min). Alternatively, vane anemometers, either swing type or propeller (revolution counting) type, can be used. Vane anemometers are generally less expensive than electronic anemometers. Light weight hand-held swing type anemometers can be easily read at various locations. The revolution counting type requires a stopwatch to calculate air velocity.

1.3.3 Humidity Gauge - The humidity in the test facility must be measured to within 3% relative humidity. Most electronic hygrometers and wet bulb hygrometers meet this accuracy specification.

The humidity gauge can also be used to monitor wood storage room humidity.

1.3.4 Barometer - Method 28A requires that the air pressure in the wood heater testing area be measured to within 3.4 mbar (0.1 in. Hg) before and after each test run. If the test facility is pressure controlled (e.g., barometric chamber), the air pressure should also be recorded every 10 min. during each test run.

Instruments capable of meeting these requirements include standard mercury barometers (visual readout), calibrated dial barometers, and electronic digital barometers. Some electronic digital barometers have an electronic readout for recorder or data logger attachment.

1.4. Apparatus and Supplies for Measuring Test Fuel Parameters

1.4.1 Apparatus and Supplies for Measuring Firebox Volume - No particular equipment is specified to measure the firebox volume; a standard tape measure can be used for most measurements. An inside caliper can be used to measure hard-to-reach areas, and a small "T" square is useful. A calculator is recommended for volume determinations.

1.4.2 Test Fuel Supplies for Wood Heater Operation

1.4.2.1 Wood Type - Only air-dried, dimensional Douglas fir of grade C or better should be used as fuel; kiln-dried lumber may not be used. Grade C is the standard structural lumber grade and is usually stamped on the lumber at the mill of origin. The user should verify that the lumber was properly graded. For grade C lumber, no more than 5% of the surface area should show knots or bark. Since most structural lumber at lumber yards has already been kiln dried, a source of air-dried Douglas fir should be arranged so that an adequate supply of fuel can be obtained. For traceability purposes, it is recommended that the source of the fuel be recorded.

1.4.2.2 Wood Size - The reference method requires the use of standard dimensional "four by fours" and/or "two by fours" with "one by two" spacers according to firebox size (actual sizes are 3 1/2 in. x 3 1/2 in., 1 1/2 in. x 3 1/2 in., and 3/4 in. x 1 1/2 in., respectively).

1.4.3 Apparatus for Test Fuel Storage - A separate temperature- and humidity-controlled room or enclosure for test fuel storage is recommended to provide for accurate test fuel temperature measurement and to maintain proper wood moisture content levels. The storage area temperature should be maintained at a constant temperature (approximately 18-32^{o}C [64-90^{o}F]) and humidity (about 90% relative humidity).

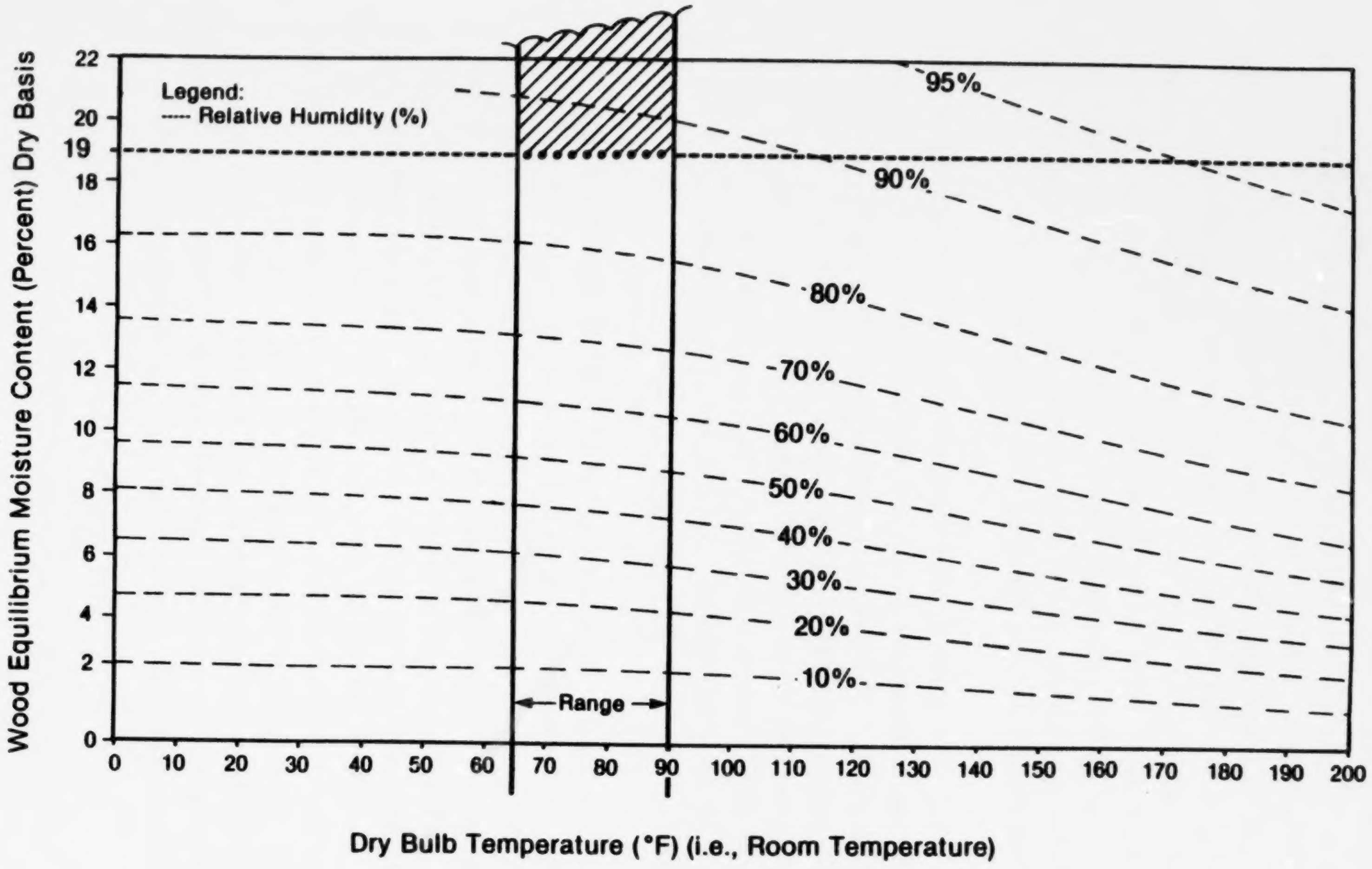
Accurate test fuel temperature measurement is important because most resistance-type moisture meter readings must be adjusted for wood temperature. Maintaining test fuel moisture content is important because if the moisture content drops below 16% wet basis (19% dry basis), the fuel may not be used for Method 28A determinations or Method 28 certification test runs; addition of moisture is not permitted. Therefore, the reliability of both the temperature and the humidity control systems in the storage area is important.

Figure 1.5 is a graph of wood equilibrium moisture content (EMC) at various storage temperatures (i.e., dry bulb temperature ^{o}F) and percent relative humidities. The desired storage temperature range is given. For example, to maintain an EMC of 19% dry basis at 18^{o}C (64^{o}F), a room relative humidity of about 86% should be maintained. Thus, in most regions, the wood storage area should have a humidifier. Some regions may require either a heat source or air conditioning. The low end of the temperature range is recommended for long-term wood storage.

1.4.4 Moisture Meter - A moisture meter is required that can measure wood moisture to ±1% moisture content in the range of 16 to 20% wet basis (19 to 25% dry basis). The reference method requires that a calibrated resistance meter be used. The electrode penetration must be 1/4 of the thickness of the test fuel piece or 19 mm (3/4 in.), whichever is larger.

Conductance meters are suitable devices for measuring wood moisture content. Dielectric meters are not acceptable because they measure at the surface and are significantly affected by the relative density of the wood (Reference: ASTM designation D4444-84).

Direct current conductance meters are commonly referred to as resistance meters. An insulated electrode with an exposed tip is required to measure moisture at the required depth; slide-hammer type electrode



Source: U.S. Forest Products Laboratory, Madison,WI

Figure 1.5. Equilibrium Moisture Content

drivers are available to facilitate wood penetration. The resistance meter should be calibrated for Douglas fir and the type of electrode pin used. Some meters are adjustable for wood temperature, while others require a temperature correction factor.

1.4.5 Test Fuel Balance (Optional) - It is recommended that a scale or balance be available for test fuel weight measurement. This balance should have a resolution of 0.05 kg (0.1 lb) or less and should have sufficient capacity for the largest anticipated test load, approximately 35 lb.

Electronic digital readout scales meet these specifications. Also, triple-beam, balance-type scales are suitable. In lieu of a separate scale or balance for test fuel loads, the wood heater platform scale may be used if it has a resolution of 0.05 kg (0.1 lb).

1.4.6 Fuel Temperature Monitor - The temperature of the test fuel must be determined by measuring the temperature of the area in which it has been stored for 24 h. This temperature must be maintained between 18 and 32°C (64 to 90°F). Since an accurate wood temperature measurement is necessary for proper wood moisture content measurement, the wood storage area temperature should remain constant for the 24-h period preceding the test crib construction. This temperature can be measured by a mercury-in-glass thermometer or by the temperature measuring device used to measure test facility temperature.

1.4.7 Apparatus and Supplies for Test Fuel Crib Construction - Method 28A requires that uncoated, ungalvanized nails or staples be used to attach the spacers to the test fuel pieces. A cutoff saw or other similar cutting device is recommended to cut the fuel to the desired lengths. Staples and staple gun, if used, should be suitable for fastening 2 cm (3/4 in.) thick spacers.

1.5 Apparatus and Supplies for Sampling and Analysis

Method 28A allows two methods to be used to measure the air-to-fuel ratio: integrated gas sampling with analysis by gas absorption (same as EPA Method 3 with Orsat analyzer) and instrumental analyzers (continuous emission monitoring system as used in EPA Method 5H). This section describes the apparatus and supplies needed for performing these procedures.

1.5.1 Integrated Gas Sampling (for Orsat Analyzer)

- Figure 1.6 shows an example of the integrated gas sampling approach. Since two bag samples must be collected simultaneously, two such systems are recommended to achieve quality control. The components are described as follows:

1.5.1.1 Probe - The probe or probe liner should have an inside diameter of about 6 mm (0.24 in.) and a length no greater than 0.6 m (2 ft). It should be equipped with either an in-stack or out-stack filter to remove particulate matter. A straight probe without a nozzle is acceptable. The main purpose of the filter is to protect the pump and rate meter. A plug of glass wool is generally a satisfactory filter. Any material inert to O_2, CO_2, CO, and N_2, and resistant to the temperatures expected at the sampling location may be used for the probe. Examples of such materials are aluminum, steel, glass, and Teflon. Since the gases to be sampled are relatively inert, the key criterion in probe selection is the stack gas temperature.

1.5.1.2 Condenser - An air- or water-cooled condenser that will not remove O_2, CO_2, CO, or N_2 must be capable of lowering the dew point of the sample gas to 5°C (40°F). A 0.63-cm (0.25-in.) stainless steel coil or equivalent connected to a water collection chamber with a capacity of about 40 mL is sufficient. The coil and chamber should be immersed in an ice bath to cool the sample to 5°C (40°F) or less.

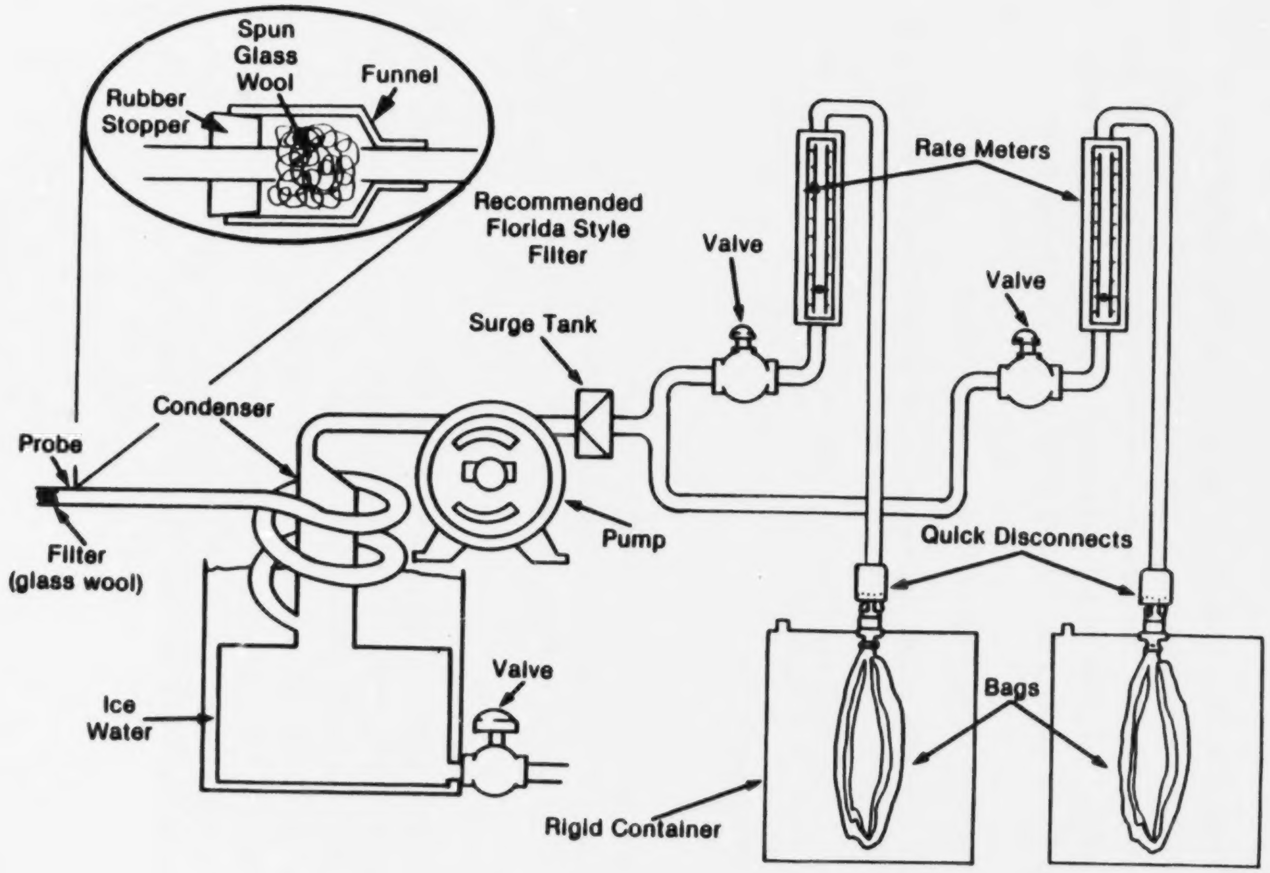

Spun
Glass
Wool
Funnel
Rubber
Stopper
Recommended
Florida Style
Filter
Rate Meters
Valve
Valve
Surge Tank
Condenser
Probe
Pump
Quick Disconnects
Filter
(glass wool)
Valve
Ice
Water
Bags
Rigid Container

Figure 1.6. Integrated Gas Sampling Train

1.5.1.3 Valve - Needle valves are needed to adjust the sample gas flow rate, one for each sample bag. They should be leak free.

1.5.1.4 Pump - A leak-free diaphragm pump, or the equivalent, is needed to transport the sample gas to the flexible bag. A small surge tank should be installed between the pump and the rate meter to eliminate the pulsation effect of the pump on the rate meter. Upon receipt, the pump, surge tank, and rate meter should be checked in the following manner:

1. Assemble the pump, surge tank, and rate meter.
2. Place a needle valve and vacuum gauge at the pump inlet using a T-connector.
3. Turn on the pump and close the needle valve until a vacuum of 125 mm (5 in.) Hg is obtained. The pumping rate at this vacuum is suggested to be at least 1 L/min (0.035 ft^3/min). The rate meter should yield steady readings when the flow is adjusted between 0.5 and 1 L/min (0.018 and 0.035 ft^3/min).

If the pump capacity is insufficient, repair, replace, or return it to the manufacturer. If rotameter readings fluctuate >2% of the full-scale reading, use a larger surge tank. Be sure that the rotameter is clean and dry.

1.5.1.5 Rate Meter - A rotameter, or an equivalent rate meter, capable of measuring flow rates within 2% of the selected flow rate should be used.

The calibration curve (Figure 1.7) supplied by the manufacturer should be checked by comparing the rotameter readings against a calibrated dry gas meter or a wet test meter reading. If the rotameter is not within 5% of the manufacturer's calibration curve, recalibrate and construct a new curve. Replace any rotameter that will not calibrate consistently.

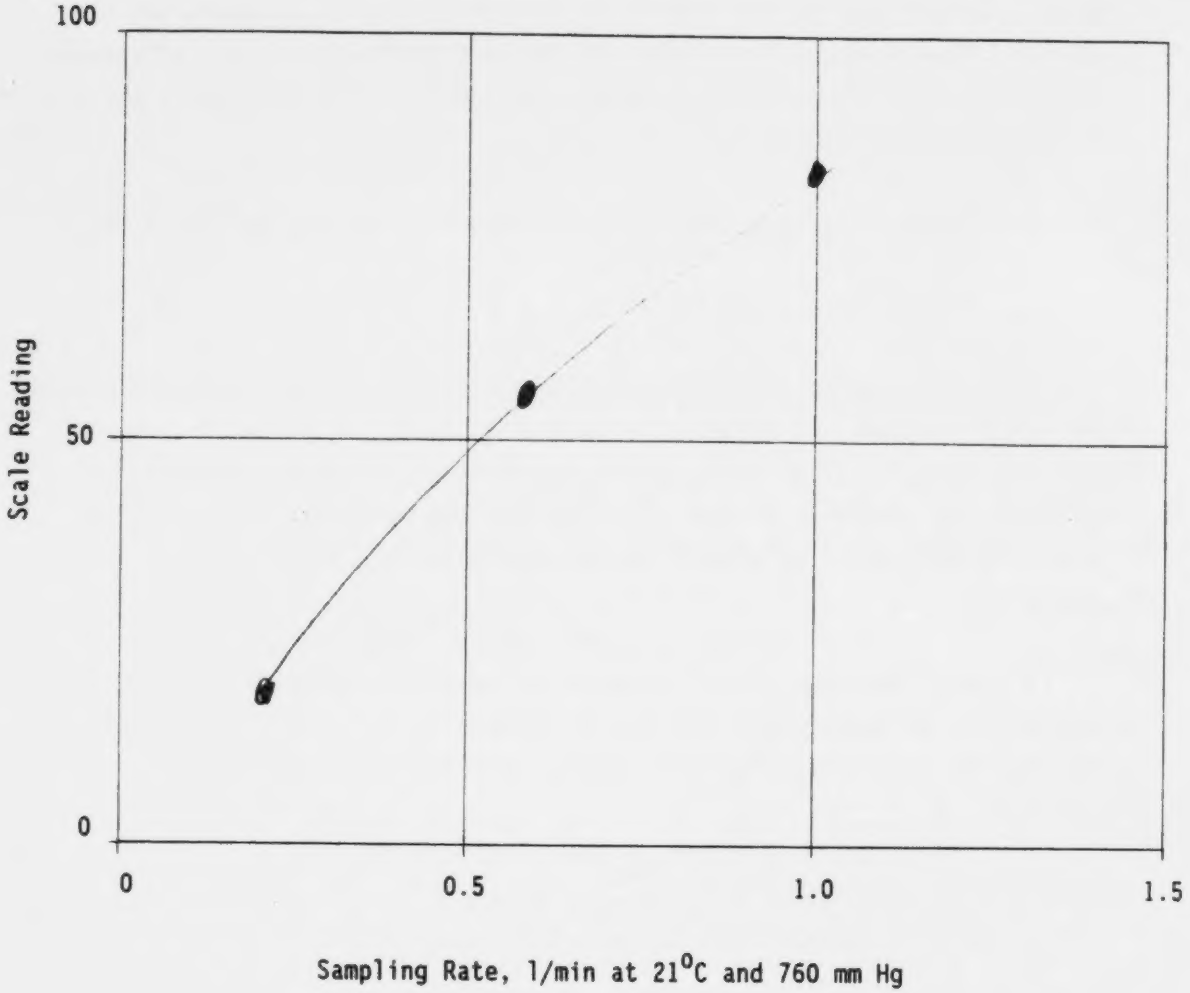


Figure 1.7. Example Rotameter Calibration Curve

1.5.1.6 Flexible Bag - Any leak-free inert plastic (e.g., Tedlar, Mylar, Teflon) bag, or the equivalent, having a capacity adequate for the selected flow rate and time length of the test run may be used. A capacity of at least 30 L (1.1 ft^3) is required for each bag. To leak check the bag, do the following (Figure 1.8):

1. Connect it to a manometer and pressurize the bag to from 5 to 10 cm (2 to 4 in.) water.
2. Allow it to stand for 10 min.

Any displacement in the water manometer will indicate a leak and a need to repair the bag. An alternative leak check is to pressurize the flexible bag to 5 to 10 cm (2 to 4 in.) water and allow it to stand overnight. A deflated bag indicates a leak. The flexible bag should be fitted with a quick-connect couple to connect to the sampling train and the Orsat analyzer.

1.5.1.7 Pressure Gauge - A water-filled U-tube manometer, or the equivalent, of about 28 cm (12 in.) is needed for the flexible bag leak check. The gauge should be leak checked upon receipt as follows:

1. Place a flexible tube on the gauge opening.
2. Apply a positive pressure of from 5 to 10 cm (2 to 4 in.) water on the gauge by blowing on and then pinching off the tube. The pressure reading should remain stable for 10 min.
3. Check each side of the gauge separately.

If a deflection is noted, repair, replace, or return the gauge to the manufacturer.

1.5.1.8 Vacuum Gauge - A mercury manometer, or the equivalent, of at least 760 mm (30 in.) Hg is needed for the sampling train leak check. If another type of gauge is used, compare the gauge reading with a mercury

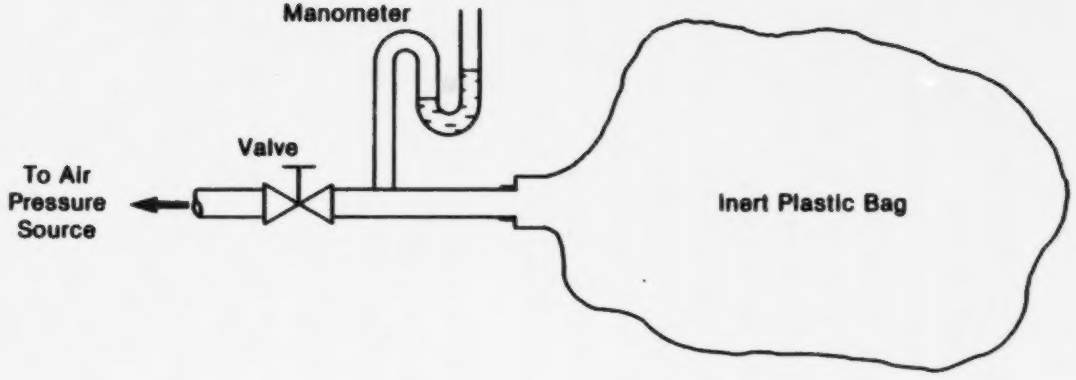

Manometer
Valve
To Air Pressure Source
Inert Plastic Bag

Figure 1.8. Plastic Bag Leak Check System

manometer reading at about 380 mm (15 in.) Hg. The gauge reading should be within ±25 mm (1 in.) Hg of the mercury manometer reading. If the gauge fails the comparison with the mercury manometer, repair, replace, or return the gauge to the manufacturer.

1.5.1.9 Orsat Gas Analyzer - The Orsat analyzer is used to determine the CO_2, O_2, and CO stack gas concentrations. A sample is analyzed by successively passing it through absorbents that remove specific gaseous components. The difference in gas volume before and after the absorption represents the amount of the constituent gas in the sample. Constant pressure and temperature must be maintained throughout the analysis. Results are reported as dry volume percentages.

The Orsat analyzer illustrated in Figure 1.9 includes a glass burette to accurately measure the gas volume, a manifold to control the gas flow, three absorption pipettes (CO, O_2, and CO_2), rubber expansion bags, and a liquid-filled leveling bottle to move the gases. For Method 28A use, the burette should have divisions of 0.1 ml at spacings of at least 1 mm (0.04 in.).

The following design features are desirable:

- Large diameter burette column (at least 30 ml volume),
- Small diameter graduated burette,
- Reference marks on the capillary tube section of the burette column and the pipette column,
- Leveling bottle and glass burette should be viewable side by side, and
- Three-way inlet manifold valve.

Upon receipt of the analyzer, wash and dry all components and assemble the apparatus according to the manufacturer's instructions. Then, properly lubricate all glass valves with silicone stopcock lubricant. If the apparatus is to be used promptly, add the liquid reagents and check for leaks as follows:

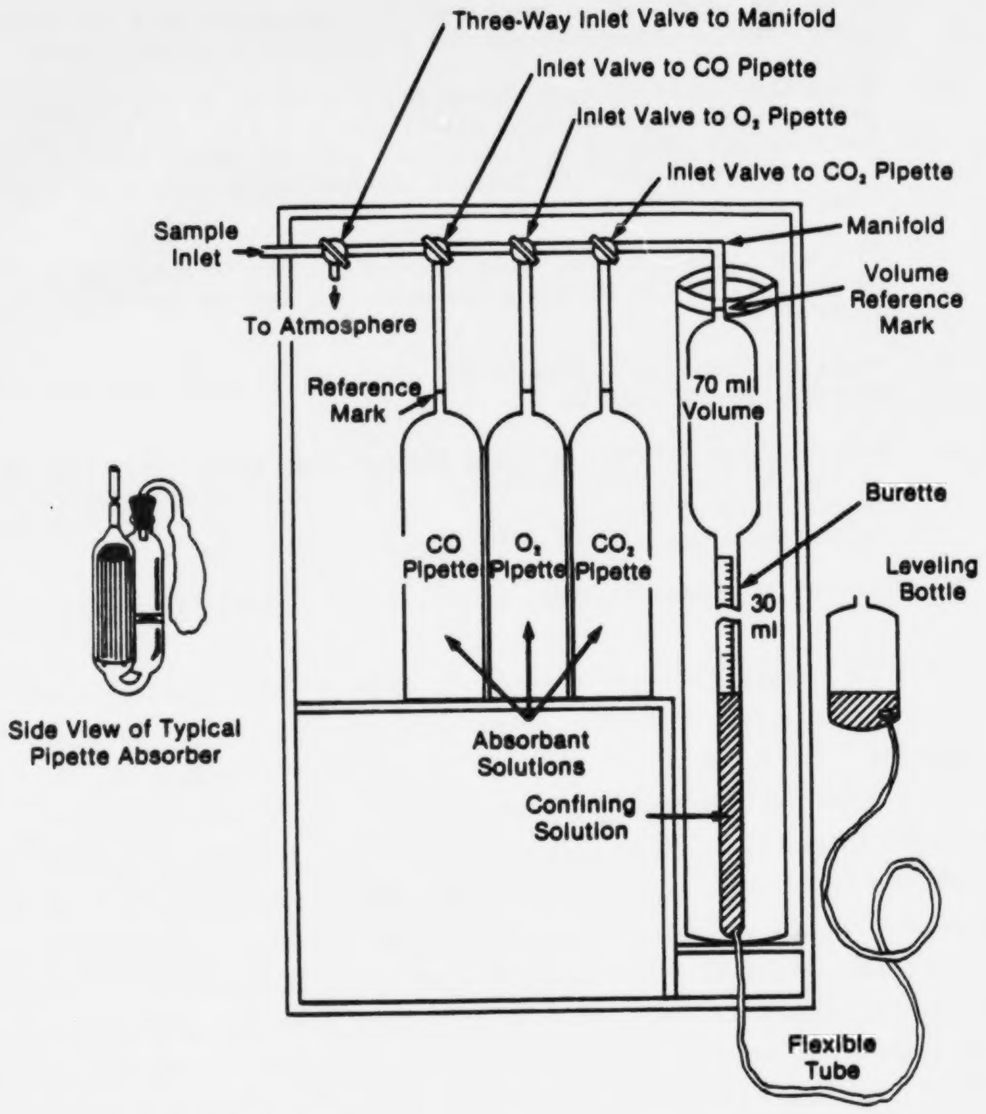

Three-Way Inlet Valve to Manifold
Inlet Valve to CO Pipette
Inlet Valve to O₂ Pipette
Inlet Valve to CO₂ Pipette
Sample Inlet
Manifold
Volume Reference Mark
To Atmosphere
Reference Mark
70 ml Volume
Burette
CO Pipette
O₂ Pipette
CO₂ Pipette
30 ml
Leveling Bottle
Side View of Typical Pipette Absorber
Absorbant Solutions
Confining Solution
Flexible Tube

Figure 1.9. Orsat Apparatus

1. Allow the apparatus to reach ambient temperature with the manifold valve open to atmosphere and the three pipette valves closed.

2. Bring the liquid in each absorption pipette up to the reference mark by opening the pipette valves one at a time and by slowly lowering the leveling bottle. Pinch off the rubber tube to the leveling bottle with the heel of the hand to quickly stop liquid flow. Close the pipette valves.

3. Displace the indicating fluid until a reading is obtained in the narrow part of the burette, and quickly close the manifold inlet valve.

4. Place the leveling bottle on top of the Orsat case, and read the meniscus in the burette.

5. Wait at least 4 min; then read the meniscus again. A change of $\geq$0.2 mL in the reading indicates a leak in the system which must be repaired. A drop in reagent level to below the capillary tube over a 4-min period indicates a leak in that pipette.

6. Correct any leak detected, or return the assembly to the supplier.

1.5.1.10 Reagents - Four reagents are required by a standard Orsat apparatus for analyzing flue gas. These are the gas-confining solution, the CO_2 absorbent, the O_2 absorbent, and the CO absorbent. Because CO_2 is soluble in water, a saturated, colored, aqueous, acidic salt solution is used as the confining solution. It contains sodium sulfate, sulfite or chloride, sulfuric acid, and methyl orange. The CO_2 absorbent is a solution of potassium or sodium hydroxide, and the O_2 absorbent is a solution of alkaline pyrogallic acid or chromous chloride. The CO absorbent is usually a cuprous chloride or sulfate solution, but other solutions may be used.[5] All of these solutions can be purchased from most chemical suppliers. Note the shelf-time requirements, because some reagents deteriorate with time.

1.5.2 Continuous Emission Monitoring System (CEMS) - As an alternative to the Orsat analyzer, Method 28A allows instrumental analyzers that measure the stack gas concentrations of O_2, CO_2, and CO continuously. CEMS is defined as the total equipment required for the determination of the gas concentration. The CEMS is composed of a sample interface, the gas analyzer, and a data recording subsystem.

1.5.2.1 Sample Interface - The sample interface is the portion of the system that collects the sample, routes the sample gas to the analyzer, and protects the analyzer from interference (i.e., faulty readings) or damage (e.g., clogging) due to the sampled stack effluent. Therefore, the specific requirements of the sample interface subsystem depend on the requirements of the analyzer. A sample interface system that is suitable for most CEMS's is shown in Figure 1.10 and consists of the following components:

1.5.2.1.1 Probe - The sampling probe should consist of a type 316 seamless stainless steel tube or a borosilicate (Pyrex) glass tube with an inside diameter (ID) of approximately 6 mm (0.24 in.) and a length not more than 0.6 m (2 ft). The sampling probe may be equipped with an in-stack or out-stack particulate filter. When an in-stack filter is used, the probe should have an expanded ID of 38 to 40 mm (1.5 to 1.6 in.) for the first 40 mm (1.6 in.) of the probe inlet. The expanded section should be packed with glass or steel wool prior to sampling. The probe outlet must have a fitting suitable for attachment to a condenser inlet or to a filter holder if an external filter is used. If the manufacturer of any of the analyzers used recommends a specific type or size filter, follow those recommendations.

1.5.2.1.2 Condenser - The condenser facilitates the condensation of water from the sample gas. The coiled tubes (as in Figure 1.6) allow the entering gas to cool to near ambient temperature; lower temperatures can be obtained by using a circulating water cooler or an ice bath.

The reservoir collects and holds the condensed water until it is drained between sampling runs by a valve. The capacity of the reservoir must be sufficient to collect all condensed moisture from the gas during system purging and sampling, but it should not be unnecessarily oversized because the added size would increase the bulk of the sampling train and lengthen purging time. The amount of water that would be collected can be estimated from knowledge of the process and the sample volume.

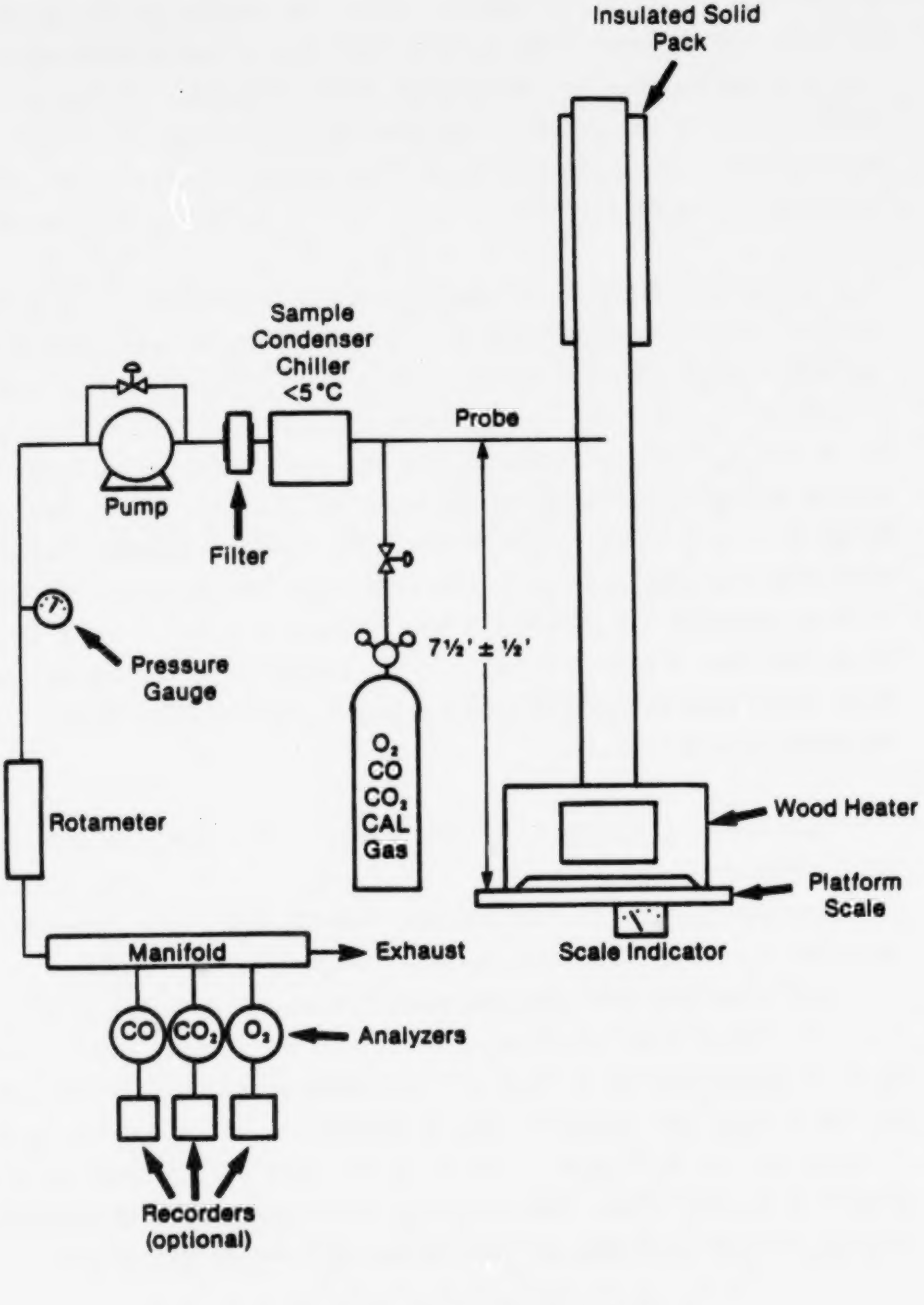

Insulated Solid
Pack
Sample
Condenser
Chiller
<5°C
Probe
Pump
Filter
Pressure
Gauge
7½' ± ½'
O₂
CO
CO₂
CAL
Gas
Rotameter
Wood Heater
Platform
Scale
Scale Indicator
Manifold
Exhaust
CO
CO₂
O₂
Analyzers
Recorders
(optional)

Figure 1.10. Example CEMS Installation

Check the condenser visually for damage, breaks, cracks, and manufacturing flaws. The condenser should be leak free at a vacuum gauge reading of 380 mm (15 in.) Hg. If the condenser is defective, repair it or return it to the supplier.

1.5.2.1.3 Needle Valve - A stainless steel needle valve with appropriate fittings to make it leak free is required to regulate the flow. Install the valve and check for proper operation. If the valve is defective or if it cannot regulate the sample flow over the 0-1 L/min (0-0.035 ft^3/min) range, repair it or return it to the supplier. A valve is not required if the gas analyzer is insensitive to flow variations or contains its own flow control system.

1.5.2.1.4 Vacuum Pump - The vacuum pump should be capable of maintaining a flow rate of 1 L/min (0.035 ft^3/min) at 380 mm (15 in.) Hg. A leak-free diaphragm pump (or the equivalent) is recommended.

A new pump should be visually checked for damage, leaks, and capacity upon receipt. To leak check the pump, install a vacuum gauge in the pump inlet line, plug the inlet line, and run the pump until the vacuum gauge reads 380 mm (15 in.) Hg; then close the pump outlet line and turn the pump off. The vacuum gauge should remain stable for 30 s. If defective, return it to the supplier. Note: Some instrumental analyzers have an internal pump.

1.5.2.1.5 Rate Meter - The rate meter is a rotameter (or equivalent) used to measure the sample gas flow rate in the range of 0-1 L/min (0-0.035 ft^3/min). Inspect the rotameter for cracks, flaws, or erratic behavior, and check calibration as described in Section 2.10. Return it to the supplier if it is damaged or cannot be adjusted to within 5% of a standard rate meter. Clean and recalibrate if dust and/or liquid contamination is suspected. A rate meter is not required if the gas analyzers used are not sensitive to sample rate variations or have their own flow measurement system.

1.5.2.1.6 Vacuum Gauge - A vacuum gauge capable of measuring at least 760 mm (30 in.) Hg is used to leak check the sampling system. A vacuum gauge is also required in the system for some analyzers. Check the vacuum gauge in a parallel leakless system with a mercury U-tube manometer at a vacuum of 380 mm (15 in.) Hg. Be sure the gauge agrees within 2.5 mm (0.1 in.) Hg. If it does not, adjust or reject.

1.5.2.2 Instrument Analyzers - A variety of instrumental analyzers meet the specifications of Method 28A. Infrared analyzers have been developed that measure O_2, CO_2, and CO. Commercially available monitors differ primarily in the design of the detector and the level of rejection of interfering gases. Polargraphic analyzers are available that measure O_2 or CO_2. Electrocatalytic and paramagnetic analyzers are available to monitor O_2. Before purchasing an analyzer, the user is urged to consult Section 3.0.9, "Continuous Emission Monitoring Systems (CEMS) Good Operating Practice" (June 1, 1986) in the Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III, Stationary Sources Specific Methods (EPA-600/4-77-027b).

1.5.2.2.1 Oxygen Analyzer - The oxygen analyzer must have a range of 0-25% O_2 by volume with a resolution of 0.125% O_2 or less. In addition, it must be able to meet the performance specifications listed in Section 2.11. A strip chart of the instrument's performance should be evaluated before purchase. The oxygen analyzer should be calibrated upon receipt according to the manufacturer's instructions and the guidelines in Section 2.11.

1.5.2.2.2 Carbon Dioxide Analyzers - The carbon dioxide analyzer must have a range of 0-5% CO_2 by volume. A lower range is acceptable if concentrations of CO_2 encountered during sampling do not exceed the instrument's range. In any case, the resolution of the instrument must be within 0.5% of the range value. For a range of 0-5% CO_2, the resolution must be 0.025% CO_2 or less. The instrument must be able to meet the performance specifications listed in Section 2.11. A strip chart of the analyzer's performance should be evaluated before purchase. Upon receipt or before use and semiannually, the performance specifications should be verified by the user. Guidelines for instrument evaluation are given in "Procedures for Testing Performance Characteristics of Automated Methods," Federal Register, Volume 40, Number 33, February 18, 1975. If the instrument is defective, return it to the manufacturer for repair, adjustment, or replacement.

1.5.2.2.3 Carbon Monoxide Analyzer - The carbon monoxide analyzer should have a range of 0-5% CO by volume, or less if actual concentrations do not exceed the instrument's range during sampling. Since carbon monoxide concentrations greater than 1.0% are likely to occur, a range of 0-5% is recommended. The resolution should be 0.025% CO or less. Before purchase, verify that the instrument is capable of meeting the performance specifications listed in Section 2.11. The calibration and performance specifications must be verified upon purchase or before use and semiannually thereafter. Guidelines for instrument evaluation are given in "Procedures for Testing Performance Characteristics of Automated Methods," Federal Register, Volume 40, Number 33, February 18, 1975. If the instrument is defective, return it to the manufacturer for repair, adjustment, or replacement.

1.5.2.2.4 Manifold - A tubing system is required that is capable of delivering the sample gas to each of three analyzers in amounts in excess of that required by each analyzer. Excess sample gas is exhausted through a separate vent. This vent should maintain a pressure in the manifold according to the requirements of the analyzers used. The manifold is generally positioned between the vacuum pump (Section 1.5.2.1.4) and the sample rate meter (if required) for each analyzer.

1.5.2.2.5 Sample Rate Meter - A separate rotameter or an equivalent rate meter is required for each analyzer unless it is demonstrated that the analyzer is insensitive to flow variations over the range encountered during the sampling. The rotameter should be positioned downstream of any flow control valve. The rotameter should be calibrated at the sampling rate of the analyzer used.

1.5.2.2.6 Needle Valve - A flow control valve should be placed upstream of each rate meter as required. The valve should be leak free and suitable for regulating a constant flow.

1.5.2.2.7 Pressure Gauge - A pressure gauge should be installed in the manifold downstream of any flow control valves. A pressure gauge is not required if the manifold vents directly to the atmosphere in the case where the analyzers draw their own gas sample. In this case, the analyzer will generally have an internal pressure gauge.

1.5.2.2.8 Special Gas Conditioning Systems - Some instrumental analyzers require gas conditioning procedures in addition to the filter and condenser already described. Usually this is because of interferent gases. For example, for some types of nondispersive infrared (NDIR) analyzers used to measure CO, any CO_2 in the gas stream will interfere with the NDIR readings. In this case, an Ascarite trap can be used to remove the CO_2 before the NDIR carbon monoxide analyzer. Follow the recommendations given by the manufacturer of the analyzer. Leak check the conditioner with the sample train according to the procedures in Section 3.3.2.

1.5.2.2.9 Recorders - Strip chart recorders or data loggers are recommended. Data loggers that provide a tape or a computer readout, and strip chart recorders provide a permanent record of test data and calibration or performance specification determinations. Before purchase, make sure the recorder is compatible with the analyzer output (e.g., voltage, impedance).

1.5.2.2.10 Calibration Gases - For each gas analyzed (i.e., O_2, CO_2, and CO), the following calibration gases are required:

- High-level gas - a gas concentration that is 80 to 90% of the upper range value of the analyzer. The upper range value is 5% for CO and CO_2 and 25% for O_2.
- Mid-level gas - a gas concentration that is 45 to 55% of the upper range value of the analyzer.
- Low-level gas - a gas concentration that is 20 to 30% of the upper range value of the analyzer.
- Zero gas - a gas concentration of less than 0.25% of the upper range value of the analyzer. For oxygen analyzers that cannot measure zero gas, an O_2 concentration of less than 2.5% may be used. Purified air may be used for CO and CO_2 zero air.

There are two alternatives for checking the concentrations of calibration gases. The first is to use calibration gases that are documented traceable to National Bureau of Standards Reference Materials. Use "Traceability Protocol for Establishing True Concentrations of Gases Used for Calibrations and Audits of Continuous Source Emission Monitors" (Protocol Number 1) that is available from the Atmospheric Research and Exposure Assessment Laboratory, Quality Assurance Division, Mail Drop 77, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Obtain a certification from the gas manufacturer that the protocol was followed. These calibration gases are not to be analyzed with the test methods.

The second alternative is to use calibration gases not prepared according to the protocol. If this alternative is chosen, within 1 month prior to the certification test, analyze each of the calibration gas mixtures in triplicate by using Method 3 for CO_2. The CO_2 and CO test results must be within 0.5% CO_2 and CO. Otherwise, discard the entire set and repeat the triplicate analyses. If the average of the triplicate test method results is within 0.5% CO_2 and CO for the CO_2 and CO gases of the calibration gas manufacturer's tag values, use the tag value. Otherwise, conduct at least three additional test method analyses until the results of six individual CO_2 and CO runs (the three original plus three additional) agree to within 0.5% of the average for both CO_2 and CO. Then use this average for the cylinder value.

Because some calibration gases with certificate of analysis have shown significant errors when compared with standard gases, good quality control procedures require the gas manufacturer to perform traceability analysis using National Bureau of Standards (NBS) Standard Reference Materials (SRMs) or gas manufacturer's Certified Reference Materials (CRMs). The EPA Traceability Protocol No. 1 should be required of the gas manufacturer for traceability analysis. A list of gas manufacturers that have prepared approved CRMs is available from EPA at the following address: List of CRM Manufacturers, U. S. Environmental Protection Agency, Quality Assurance Division (MD-77), Research Triangle Park, North Carolina 27711.

Calibration gases must be certified by the gas manufacturer to within 2% of the specified concentration. Do not store gas cylinders in areas subject to extreme temperature changes. Before each calibration, check the cylinder pressure of each calibration gas and replace any with <1400 kN/m^2 (200 psi) pressure.

1.5.2.2.11 Silica Gel - Indicating type 6 to 16 mesh should be dried at $175^{o}C$ ($347^{o}F$) for at least 2 h. The color should be blue when the water has been removed.

1.5.2.2.12 Ascarite - Ascarite (20 to 30 mesh) is commercially available. It consists of asbestos coated with sodium hydroxide which forms sodium carbonate when exposed to CO_2. Eventually, the Ascarite is spent and has to be replaced since it cannot be regenerated.

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Steel flue pipe	Diameter as specified by wood heater manufacturers; no dents or damaged flanges	Visually check upon purchase	Repair or return to supplier
Insulated solid pack chimney (ISP)	Same diameter as steel flue pipe; insulation no more than 2.5 cm (1 in.) thick; meets UL 103 requirements; no damage to insulation or flanges	Visually check upon purchase. Check with manufacturer as to UL 103 requirements	Repair or return to supplier
Liquid seal (optional)	Airtight, frictionless couple; no liquid leaks; no dents or damaged flanges	Visually check and leak test upon purchase	Repair or return to supplier
Miscellaneous:			
Liquid seal oil	High boiling point; low evaporative rate	Check manufacturer's specifications	Replace with suitable material
Equipment for supporting pipe and ISP	Meets ISP manufacturer's recommendations	Check upon purchase	Replace with suitable material
High-temperature sealant	Suitable for temperature anticipated at point of use	Check specifications upon purchase; inspect upon first test run	Replace with suitable material
Hand tools and fasteners	As required	As required	Replace with suitable material

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Flue pipe adapter sections	Must fit tightly and securely	Check visually upon assembly	Replace as necessary
Platform scale	Capacity for anticipated wood heaters plus flue and test fuel; resolution of 0.05 kg (0.1 lb) or 1% of test fuel weight (whichever is larger)	Upon purchase (manufacturer's certification is acceptable) and before each test (see Section 2.0)	Recalibrate or return to supplier
Draft gauge	Able to read 1.25 Pa (0.005 in. H_2O) with resolution of 0.5 Pa (0.002 in. H_2O)	Check for damage and calibrate upon receipt (see Section 2.0)	Adjust or return to supplier
Temperature monitors:			
Test facility and fuel storage area	Monitor room temperature 18-30°C (64 to 90°F) accurate to ±1.5% absolute temperature	Check for damage and calibrate upon receipt	Repair or return to supplier
Miscellaneous:			
Calibration weights	Class F accuracy; 20 to 80% of anticipated test loads	Check upon receipt	Replace with suitable material
Heat insulation	Protect platform scale as required	Check upon receipt	Replace with suitable material

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Anemometer	Able to read to an air velocity of 0.1 m/s (20 ft/min)	Visually inspect and calibrate upon receipt	Recalibrate or return to supplier
Humidity gauge	Able to read to ±3% relative humidity	Visually inspect and calibrate upon receipt	Recalibrate or return to supplier
Barometer	Resolution of 3.4 mbar (0.1 in. Hg)	Visually inspect and calibrate upon receipt	Recalibrate or return to supplier
Test fuel	Air-dried, dimensional Douglas fir; moisture content 19-25% (dry basis). As specified by Method 28, Section 4.2.1.	Visually inspect and measure moisture upon receipt	Return if not as specified; return if below 19% moisture content (dry basis); accept if more than 25% moisture content (dry basis) but air dry to acceptable level
Moisture meter	Able to read moisture content from 16-20% (wet basis) or 19-25% (dry basis) to ±1% moisture content in Douglas fir at depth up to 2.5 cm (1 in.)	Visually inspect and calibrate upon receipt	Recalibrate or return to supplier

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Wood storage area	Able to maintain temperature to ±4°C (8°F) absolute between 18 and 32°C (64 and 90°F) for 24 h; able to control humidity to maintain fuel moisture content	On construction and as required	Replace or repair
Apparatus and supplies for test fuel crib construction	As required	Upon purchase	Replace
Integrated Gas Sampling Train:			
Probe	Stainless steel, borosilicate glass, or equivalent; no leakage	As above	As above
Condenser	Capable of reducing dew point to 5°C (40°F); no leakage	As above	As above
Valve (two required)	Needle valve	As above	As above
Pump	Diaphragm type, leak free, and 1 L/min (0.035 ft^3/min) capacity	Check for leaks and capacity upon receipt	As above

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Rate meter (rotameter) (two required)	Check flow range from 0 to 1 L/min (0 to 0.035 ft^3/min) must be accurate to within 5% of selected flow rate	Check upon receipt for damage; calibrate against dry gas meter	Recalibrate and construct new calibration curve
Flexible bag (two required)	Capacity >30 L (1.1 ft^3); leak test not mandatory	Check for leaks and capacity	Return to supplier
Pressure gauge	28-cm (12-in.) water-filled U-tube or equivalent for flexible bag leak check	Visually observe and leak check upon receipt	As above
Vacuum gauge	At least 760-mm (30-in.) Hg gauge for the sampling train leak check	Check against a mercury U-tube manometer and leak check	As above
Orsat Analyzer			
Glass burette	0.1-mL divisions with spacings of about 1 mm	Visually inspect upon receipt	Return to supplier
Pipettes, manifolds, etc.	Airtight	Leak check initially and before tests	Repair or discard
Leveling bottle	Can be viewed side-by-side with glass burette	Visually check for damages	As above

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Absorbants	CO_2: potassium or sodium hydroxide O_2: alkaline pyrogallol or chromous chloride CO: cuprous chloride or sulfate solution Gas-confining solution: saturated sodium sulfate, sulfuric acid, and methyl orange	Reject if absorption decreases	Replace with fresh solution
Continuous Emission Monitoring System (CEMS)			
Sampling probe	Stainless steel (316) or sheathed Pyrex glass with filter to remove particulate matter; no damage, cracks, or breaks; leak free at 380 mm (15 in.) Hg	Visually check for length and composition ordered; leak check upon receipt	Repair or return to supplier
Condenser	Capacity sufficient to collect all condensed moisture from the sample gas; no damage, cracks, or breaks, leak free at 25 mm (1 in.) H_2O positive pressure and at 380 mm (15 in.) Hg vacuum	Check for size and damage; leak check upon receipt	Repair or return to supplier

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Needle valve	Stainless steel; capable of regulating the flow rate over the range of 0-1 L/min (0-0.035 ft^3/min); leak-free fittings	Install in sampling train; check for proper operation; leak check upon receipt	Repair or return to supplier
Vacuum pump	Leak-free diaphragm at 380 mm (15 in.) Hg or equivalent; capable of maintaining a flow rate of 1 L/min (0.035 ft^3/min) or greater than the requirements of the analyzers	Leak check; check for damage and capability of maintaining desired flow rate	Return to supplier
Rate meter	Rotameter or equivalent; no cracks, flaws, or erratic behavior; measure gas flow in the range of 0-1 L/min (0-0.035 ft^3/min); agree within 5% of standard rate meter	Check for cracks and flaws and calibrate against a wet test meter (Section 2.10)	Return to supplier
Barometer	Capable of measuring atmospheric pressure to ±2.5 mm (0.1 in.) Hg	Check against a mercury-in-glass barometer or equivalent	Determine correction factor or reject
Vacuum gauge	0-760 mm Hg range ±25 mm (1.0 in.) at 380 mm (15 in.) Hg	Check against a U-tube mercury manometer upon receipt	Adjust or return to supplier

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Sample Analysis			
Instrumental analyzers	NDIR spectrometer or equivalent; meets specifications in Section 2.11	Have supplier (1) demonstrate that it meets or exceeds performance specs, and (2) provide a strip chart record of runs	Return to supplier for repair, adjustment, or replacement
Drying tube (if required)	Capacity of at least 200 g of silica gel; leak free at 380 mm (15 in.) Hg	Check upon receipt for proper size; leak check	Repair or return to supplier
Filter and holder	Type and size recommended by analyzer manufacturer, or glass fiber filter	Check upon receipt for proper size and type	Return to supplier
CO_2 removal tube (if needed)	Contains 400 g of ascarite; leak free at 380 mm Hg (15 in.); may combine silica gel and CO_2 removal tubes	Check upon receipt for proper size, fittings, and leak check	Return to supplier
Recorders (optional)	Strip chart recorder with operating voltage compatible with analyzer, or an equivalent data logger	Check for damage and proper operation over entire voltage range	Return to supplier

TABLE 1.2. ACTIVITY MATRIX: PROCUREMENT OF APPARATUS AND SUPPLIES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Reagents			
Calibration gases	Certified by manufacturer to ±2% of specified concentration; traceability to NBS/SRM or CRM (in N_2)	Traceability analysis required of the gas manufacturer using EPA Traceability Protocol No. 1	Return to supplier
Silica gel	Indicating type 6 to 16 mesh; blue in color	Dry at 175°C (347°F) for at least 2 h prior to use	Discard or return to supplier
Ascarite (if needed)	20 to 30 mesh	Check label for correct type	Return to supplier, discard when spent

2.0 CALIBRATION OF APPARATUS

Calibration of apparatus is an important factor in maintaining data quality. This section describes the calibration procedures for the equipment described in the previous section. Subsections 2.1 through 2.8 describe calibration of process measurement equipment, while Subsections 2.9 through 2.11 describe the calibration of sampling and analytic equipment. To facilitate data recording, a logbook of all calibrations should be maintained that includes a calibration log for each piece of equipment. Blank calibration sheets are provided in Section 12.0 for the convenience of the user. Table 2.1, at the end of this section, summarizes the quality assurance activities for calibration.

2.1 Platform Scale and Monitor

2.1.1 Frequency and Specifications of Calibration - Upon purchase or before the first applicability determination test, the platform scale must be calibrated with five calibration weights spanning the operational range of the scale. For this initial calibration, the manufacturer's calibration certification is acceptable for a new scale.

Before each subsequent applicability determination test, a single-point calibration check must be made with a Class F calibration weight that is between 20 and 80% of the test load weight. If the scale cannot reproduce the certified Class F weight within 0.05 kg (0.1 lb), then the scale must be recalibrated with a five-point calibration according to the manufacturer's instructions.

2.1.2 Method of Calibration - Different scales require different methods of calibration. The scale manufacturer's instructions should be followed closely. This subsection gives the general procedure required by Method 28A.

Before beginning the single-point calibration check required before the applicability determination test, the wood heater with flue pipe and liquid seal (if used) should be assembled for testing. The scale should then be "tared" (i.e., set to zero reading). For scales without a tare feature, the weight of the wood heater assembly should be recorded before each subsequent single-point calibration check in case the weight reading has drifted. The Class F calibration weight should then be placed centrally on the scale or wood heater. This weight reading (or weight difference) should be within 0.05 kg (0.1 lb) of the certified weight.

If the scale does not have a resolution small enough to verify this tolerance, the Class F weight must be reproduced to within 0.00 kg (lb). For example, if a 10.0 lb Class F weight standard is used to calibrate a scale with a resolution of 0.1 lb, the scale reading can be either 9.9 lb, 10.0 lb, or 10.1 lb and still be acceptable. However, if a scale with a resolution of 0.2 lb is used, the scale must read exactly 10.0 lb for a 10.0-lb Class F weight standard; 9.8 lb or 10.2 lb is not acceptable.

Some scales provide for a span adjustment with the tare weight (i.e., wood heater) in place. For these scales, if the Class F weight is not reproduced within the allowed tolerance, the span should be readjusted and the tare reset according to the manufacturer's instructions. The scale should then be checked with the Class F weight. If the scale reading is then within the allowed tolerances, the single-point pretest calibration check requirement has been met.

If this single-point calibration check cannot be met within the allowed tolerance with a tare-in-place span adjustment, then the scale must be recalibrated by using five test weights spanning the operational range of the scale. The scale manufacturer's recommendations should be followed. In lieu of purchasing certified Class F calibration weights for full-scale calibrations, various companies offer scale calibration and maintenance services.

The platform scale should be tared before each applicability determination test because some scales may experience a change in tare "memory" after several days if a heavy weight (e.g., wood heater) is left in place. The span check (i.e., single-point calibration) is also recommended at this time to help ensure good data quality. A post-test calibration check after the test run is also recommended.

Temperature can affect platform scale calibration so the calibration should be checked at the operating temperatures expected during the test. The pretest burn is an appropriate time to perform this calibration check. An insulated pad between the platform scale and the wood heater can help stabilize the platform scale temperature. For scales that have a designated temperature operating range, a temperature monitor should be placed on the platform to determine if the operating temperature has been exceeded.

All calibration checks and adjustments should be recorded on a calibration sheet such as that shown in Figure 2.1. Blank forms are supplied in Section 12.0 for this purpose.

2.2 Test Fuel Balance (Optional)

2.2.1 Frequency and Specifications of Calibration - The balance must be calibrated upon purchase and before each applicability determination test. Calibration should be checked to ±0.05 kg (0.1 lb) before weighing each test load crib.

2.2.2 Method of Calibration - Calibration should be checked with a Class F calibration standard weighting between 20 and 80% of the test load weight. The balance manufacturer's recommendations should be followed for calibration adjustments. Following adjustments, recheck the balance weight readings with the Class F weight. Record all calibration checks and adjustments on a calibration sheet such as Figure 2.1. Maintain a separate calibration record sheet for each scale or balance.

2.3 Facility Temperature Monitor

2.3.1 Frequency and Specifications of Calibration - The temperature monitors must be checked for calibration before the first applicability determination test (or upon purchase) and semiannually thereafter. The temperature monitoring device should reproduce reference temperatures to within 1.5% of the absolute temperature (i.e., K or R).

Scale Model: Platform ✓
Balance ____

Capacity 1000 lb
Resolution 0.1 lb

Test Facility ABC Testers
Date 3/30/88

1988 Date	Wood Heater	Platform Temperature	Class F Calibration Weight (A)	Initial Scale Reading or Tare (B)	Final Scale Reading (C)	Measured Calibration Weight (D = C - B)	Difference (D minus A)	Action Taken	Calibrated By
3/30	Firebox	125°F	15 lb	650.5	665.4	15.4	-0.1	OK	J.S.

Figure 2.1. Scale Calibration Record Sheet

2.3.2 Calibration Procedures - The temperature monitor should be calibrated against a mercury-in-glass thermometer which meets American Society for Testing and Materials (ASTM) E-1 No. 63C or 63F specifications. Alternatively, a reference thermocouple and potentiometer certified by the NBS or thermometric fixed points may be used.

The thermometric fixed point reference method can be used with or without an ASTM mercury-in-glass reference thermometer. With an ASTM thermometer, the reference thermometer should be compared with the temperature sensor at two points. For room temperature sensors, room temperature and a water-ice bath are suitable points. The reference thermometer and the temperature sensor should agree to within 1.5% of the absolute temperature at each point. Figure 2.2 is an example of a calibration sheet using an ASTM reference thermometer.

Without an ASTM thermometer, a water-ice bath (i.e., $0^{o}C$ or $32^{o}F$) and boiling water may be used as the two reference temperatures. However, deionized water should be used for the ice bath, and the boiling water temperature must be adjusted for barometric pressure. The temperature sensor should agree with both fixed points to within 1.5% of the absolute temperature.

All measurements and actions taken should be recorded semiannually on a calibration record sheet.

2.4 Anemometer

2.4.1 Frequency and Specifications of Calibration - The anemometer calibration should be checked before the first applicability determination test (or upon purchase) and semiannually thereafter or per the manufacturer's instructions. The anemometer should have a resolution of ±0.1 m/s (20 ft/min) at 0.25 m/s (50 ft/min) and should be able to measure air velocities as low as 0.10 m/s (20 ft/min).

2.4.2 Method of Calibration - Anemometers can be calibrated by either of two methods in accordance with EPA Method 14, Section 4.1.1: (1) direct calibration by comparison with an NBS traceable anemometer or

Temperature Monitor Type Thermocouple
Identification Number TC #1
Readout Device Digital

Test Facility ABC Testers
Reference Temperature Monitor N/A
Identification Number

Date	Temperature Reference Point Source[1]	Observed Temperature		Difference[3] (% R or K)	Action Taken	Calibrated By
		Reference:[2] Fixed Point or Reference Monitor (A)	Measured: Temperature Monitor Reading (B)			
3/30	ice water	32°F	28°F	0.8 %	OK	J.S
"	boiling water	208.9°F	190°F	2.8 %	replace TC	
	"	"	192°F	2.6 %	adjust span	
	"	"	209°F	0.0 %	OK	

[1] Reference points include ice bath, boiling water, furnace, etc.

[2] Boiling point H_2O in °C = 100 - .94 (29.92 - barometric pressure in in. Hg). (Pb = 28.10)
Boiling point H_2O in °F = 212 - 1.69 (29.92 - barometric pressure in in. Hg).

[3] Difference in %K = (A - B) / (A + 273) x 100 for A and B in °C; %R = (A - B) / (A + 460) x 100, for A and B in °F

Figure 2.2. Temperature Monitor Calibration Record Sheet

(2) calibration by direct measurement (e.g., by moving the anemometer through still air at a measured rate of speed and recording the output). It is recommended that the calibration be checked at 0.25 m/s (50 ft/min) and at the lowest measurable anemometer response or threshold level. This threshold level must be less than 0.10 m/s (20 ft/min).

For propeller-type anemometers, the threshold torque (force required to turn a stationary propeller) should be less than that corresponding to a velocity of 0.10 m/s (20 ft/min). The user should make sure that the propeller is not stuck by spinning it manually before calibration and use. The calibration should be recorded semiannually on a form such as Figure 2.3.

Alternatively, Method 28 allows the calibration procedure recommended by the manufacturer.

2.5 Barometer

2.5.1 Frequency and Specifications of Calibration - The barometer should be calibrated before the first certification test and semiannually thereafter. The barometer should be accurate to within 2.5 mm Hg (0.1 in. Hg). Mercury-in-glass barometers do not require calibration.

2.5.2 Method of Calibration - The barometer should be calibrated against a mercury-in-glass barometer or the equivalent. In lieu of this, the absolute barometric pressure may be obtained from a nearby National Weather Service (NWS) station. Usually, the NWS value is already adjusted to sea level. This value must be corrected to the absolute barometric pressure at the testing facility elevation. After determining if the NWS value has been adjusted for sea level, the procedure is either to subtract 2.5 mm Hg/30 m (0.1 in. Hg/100 ft) from the station value for an elevation increase or add 2.5 mm Hg/30 m (0.1 in. Hg/100 ft) for an elevation decrease. If the barometer cannot be adjusted to agree to within 2.5 mm Hg (0.1 in. Hg) of the reference barometric pressure, it should be returned to the manufacturer or replaced. Semiannually, a record of all measurements and corrective actions taken should be made on a calibration sheet. A form similar to Figure 2.3 is provided for this purpose in Section 12 of this document.

Instrument to be Calibrated Anemometer
Model Number vane type

Test Facility ABC Testers
Calibration Performed By J.S

Date	Method of Measurement	Reference Value (A)	Measured Value (B)	Difference (A minus B)	Acceptable Tolerance	Action Taken
3/30	50 foot walk in still air	50 ft/min	30 ft/min	20 fpm	± 20 ft/min	OK

Figure 2.3. Semiannual Calibration Record Sheet

2.6 Draft Gauge

2.6.1 Frequency and Specifications of Calibration - The draft gauge must be calibrated before the first certification test and semiannually thereafter. The gauge should be accurate to ±0.5 Pa (0.002 in. H_2O) at 1.25 Pa (0.005 in. H_2O). The calibration should be checked in the range from 1.25 to 25 Pa (0.005 to 0.10 in. H_2O).

2.6.2 Method of Calibration - Electronic manometers should be calibrated against a liquid manometer and adjusted according to the manufacturer's instructions. Liquid manometers do not require calibration. They should, however, be checked for proper liquid level. Semiannually, the calibration data should be recorded on a form such as Figure 2.3.

2.7 Humidity Gauge

2.7.1 Frequency and Specifications of Calibration - The humidity gauge should be calibrated before the first certification test and semiannually thereafter. The gauge should be accurate to ±3% relative humidity.

2.7.2 Method of Calibration - Humidity gauges should be calibrated according to the manufacturer's instructions. Semiannually, the calibration data should be recorded on a form such as Figure 2.3.

2.8 Wood Moisture Meter

2.8.1 Frequency and Specifications of Calibration - Since wood moisture measurement directly affects the burn rate determination, the wood moisture meter must be calibrated before each applicability determination test. Ideally, the meter should be calibrated each time it is used to measure the test fuel moisture. The meter should be accurate to ±1% moisture reading.

2.8.2 Method of Calibration - A resistance-type meter should be calibrated against known resistances according to the manufacturer's specifications. The resistances should be set for Douglas fir and for the type of electrode pins used. Before calibration, the electrode insulation should be checked for breaks. Insulation breaks will bias a reading to the highest moisture if a moisture gradient exists in a wood sample. Electrodes should be visibly clean. The temperature of the moisture meter should be allowed to equilibrate to the approximate fuel temperature.

At least two resistances should be used to calibrate the meter. Resistances corresponding to 19 and 22% moisture content (dry basis) are recommended. The calibration should not be extrapolated below the lowest value (i.e., the lowest value resistance should correspond to no more than 19% moisture content [dry basis] or 16% [wet basis]). Extrapolation above 21% moisture content (dry basis) is allowed if a resistance corresponding to 21% or more is used. Moisture level readings greater than 25 to 27% moisture content (dry basis) cannot be measured with confidence. The calibration data should be recorded on a form such as Figure 2.4.

2.8.3 Oven-Drying Method - The oven-drying method is the universally accepted method for determining moisture content in wood seasoning operations such as air drying. Since oven drying is a destructive process (i.e., the wood tested cannot later be used as a test fuel), it is of use only to check the accuracy of wood moisture measurement methods.

The procedure is as follows:

1. Cut representative samples of the test fuel and measure with the resistance meter according to Method 28A (i.e., on three sides). Record the temperature of the test fuel and adjust moisture content reading if necessary.
2. Weigh on a balance to an accuracy of ±0.2% sample weight.
3. Heat in an oven at 103 ± 2°C (217 ± 4°F) until weight changes less than 0.2% of the original sample weight in a 2-hour period. Avoid drying longer than necessary.

Moisture Meter Type ____________

Model Name Wet Wood 200

Model Number 600

Operating Temperature 68°F

Test Facility ABC Testers

Calibration Performed By JDS

Date of Calibration ____________

Reference Source	Moisture Content Equivalent of Reference Source (A)	Moisture Meter Reading (B)	Difference (Should be within 1%) (A minus B)	Action Taken
Bar #1	22% MC (Dry)	20% MC	2% MC	clean pins
"	"	21.5% MC	0.5%	OK
Bar #2	19% MC	18.5%	0.5%	OK

Figure 2.4. Moisture Meter Calibration Sheet

4. Calculate moisture content as follows:

   percent (dry basis) = [(A - B)/B] x 100

   where: A = original weight
   B = oven-dry weight

5. Compare this value with the moisture content (dry basis) determined by the moisture meter. If necessary, calibrate the moisture meter and recheck with the calibration resistance. Note the corrected resistance/moisture relationship for future calibration checks.

2.9 Orsat Analyzer

2.9.1 Frequency and Specifications of Calibration - Only limited initial calibration is required for gas absorption using an analyzer such as an Orsat. Continued maintenance, reagent checks, and most important, the operator's technique and diligence are required for good quality data. Calibration is recommended upon receipt, before every third test, and before any test in which the Orsat analyzer has not been checked during the previous 3 months. In addition, the calibration should be checked following each test. The specifications required are discussed below.

2.9.2 Method of Calibration - To check the O_2-absorbing reagent and the operator's technique, the percentage of O_2 in air should be determined. The average of three replicates should be 20.8 ± 0.7% when using the standard Orsat. A measured average value of >21.5% generally indicates poor operator technique, while a value of <20.1% generally indicates leaking valves, spent absorbing reagent (for O_2 only), and/or poor operator technique. The three replicates and their averages should be reported on an $\bar{X}$ and R chart, as illustrated by Figure 2.5. The mean of at least three absorption passes is represented by $\bar{X}$ and the range (i.e., maximum minus minimum) by R. A blank copy of this form is in Section 12.

A more thorough check, if required equipment is available, would be to take a sample from a manifold containing a known mixture of CO_2 and O_2. The sample is analyzed for CO_2 and O_2 using the Orsat. The average of three

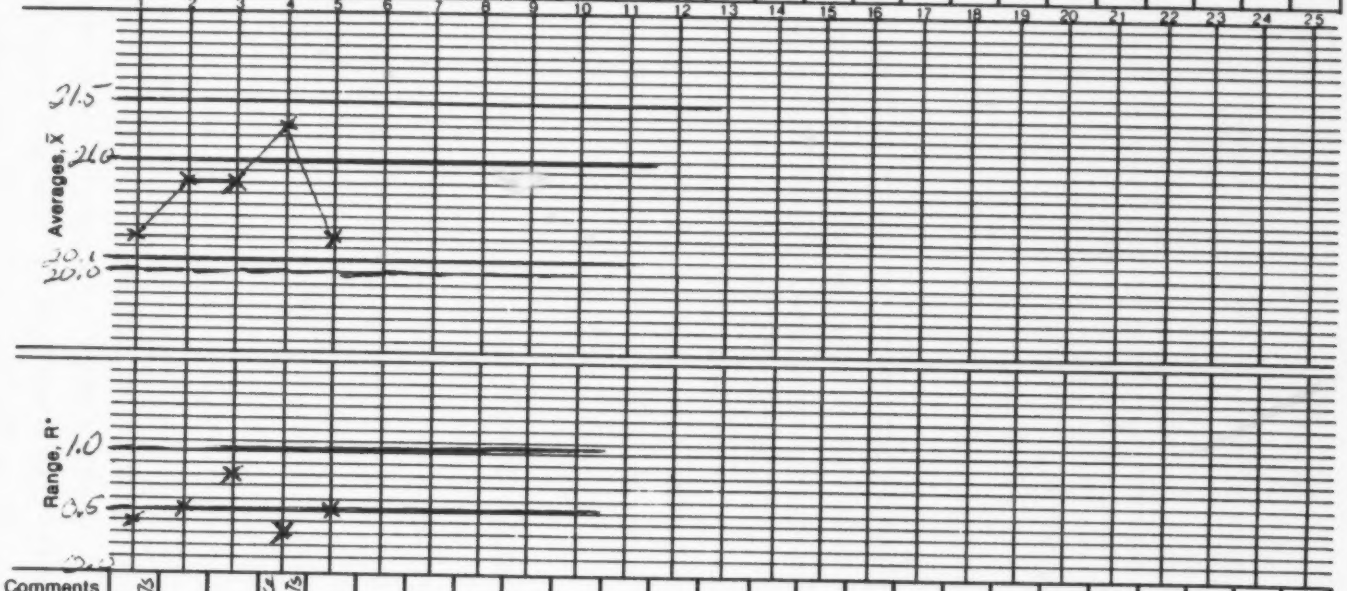
Reproduced from best available copy.

Project Name: Orsat Calibration

Measurement Performed: AIR

Measurement Units: Percent vol/vol

Date	3-1-88	3-12-88	4-1-88	4-8-88	4-15																				
Measurement Code 1																									
Measurement Code 2																									
Measurement Code 3																									
Measurement Result 1	20.5	21.1	20.4	21.5	20.6																				
Measurement Result 2	20.3	20.8	21.2	21.2	20.1																				
Measurement Result 3	20.1	20.6	20.9	21.3	20.2																				
Sum	60.9	62.5	62.5	64.0	60.9																				
Averages, $\bar{X}$	20.3	20.8	20.8	21.3	20.3																				
Range, R*	0.4	0.5	0.8	0.3	0.5																				



Comments (correct action, etc.)	New reagents			replace reagents																					

* Maximum result minus minimum result

Figure 2.5. $\bar{X}$ and R Chart

replicates should be ±0.5% (absolute) of the known concentration of each gas. For example, if CO_2 in the known mixture is 8.5%, the measurement by the Orsat must be 8.0 to 9.0% CO_2. Again, high measured values indicate poor operator technique, while low values indicate leaking valves, spent absorbing reagent, and/or poor operator technique.

If the above limits are exceeded, corrective action should be equipment maintenance and/or operator training.

2.10 Rotameter

2.10.1 Frequency and Specifications of Calibration - Clean and calibrate the rotameter or other rate meter in the integrated gas sampling train every 6 months and at any sign of erratic behavior. The rotameter must read within 5 percent of the actual flow as described below.

2.10.2 Method of Calibration - Calibrate with either a wet test meter or a volume meter which has been recently calibrated against a primary standard.

1. Place the calibrated volume meter or wet test meter in series with the rate meter.
2. Start the air flowing at 0.5 L/min (0.02 ft^3/min).
3. Record the barometric pressure (P_B) on the rotameter calibration sheet (Figure 2.6).
4. Adjust the flow (R_s) to 0.10 L/min (0.0035 ft^3/min) with a needle valve.
5. Use a stopwatch to measure the time (θ) required to make at least two revolutions of the wet test meter dial.
6. Repeat Step 4 with the flow (R_s) adjusted to 0.25, 0.50, 0.75, and 1.0 L/min (0.009, 0.018, 0.027, and 0.035 ft^3/min) going from a flow of 1.0 to 0.10 L/min. Record the time, the rotameter reading (R_s), the elapsed time of the run (θ), the temperature of the liquid in the reference meter (t_w), the manometer reading at the reference meter (D_m), and the total volume displaced for each run (V_w).
7. Calculate the volume (V_r) at standard temperature and pressure (STP) conditions for each test point and record on Figure 2.6.

Rotameter Serial Number 2645

Location ABC Testers

Barometric Pressure, P_B, 29.9 in. Hg

Wet Test Meter Number WTM-1

Date 3/30/88

Calibrated By J. S.

R_s, ft^3/min	θ, min	t_w, °F	D_m, in. H_2O	V_w, ft^3	V_r, ft^3	Q_s, ft^3/min
0.027	3	68	-0.1	0.081	0.081	0.027

R_s = rotameter setting, ft^3/min (e.g., 0.009, 0.018, 0.027)

θ = time of calibration run, min

t_w = temperature of the gas in wet test meter, °F

D_m = pressure drop on the wet test meter, in. H_2O (a negative number if calibrated as in Figure 2.3)

V_w = gas volume passing through wet test meter, ft^3

V_r = gas volume passing through the rotameter corrected to STP, ft^3

Q_s = flow rate through rotameter, corrected to STP, ft^3/min

t_s = standard temperature, 68°F

P_s = standard pressure, 29.92 in. Hg

$$V_r = \frac{V_w (P_B + D_m / 13.6)(t_s + 460)}{(t_w + 460) P_s} = \frac{17.65 V_w (P_B + D_m / 13.6)}{(t_w + 460)} = ft^3 \text{ at STP}$$

$$Q_s = \frac{V_r}{\theta} = ft^3/\text{min at STP}$$

Figure 2.6. Rotameter Calibration Data Form

8. Calculate the standard flow rate (Q_s) for each test point and record on Figure 2.6.

9. Plot the rotameter setting (R_s) versus the flow rate (Q_s) on linear graph paper by using a flexible rule to construct a best-fit smooth curve through the data points. Note: A typical relationship is shown in Figure 2.7. All data points should be within ±2% of the best-fit curve.

2.11 Instrumental Analyzers

Many different instrumental analyzers are commercially available that meet the requirements of Method 28A. Because the calibration procedures, and even the sampling system configurations, may differ for these analyzers, this manual does not attempt to describe all such procedures. The user must follow the procedures recommended by the manufacturer. Also, the user should refer to Section 3.0.9, "Continuous Emissions Monitoring Systems (CEMS) Good Operating Practices," in Reference 6.

This section lists the calibration and performance specifications that must be met. General calibration procedures are given that apply to most systems. One instrumental analyzer, a nondispersive infrared analyzer, is used as an example. However, requirements vary for different instruments. For example, CO_2 may be removed (scrubbed) internally by some analyzers, but for other analyzers, CO_2 does not interfere with CO.

In general, the system should be calibrated at the same temperature, pressures, and flow rates encountered during sampling. Also, the calibration gases should follow the same route as the sample gas (i.e., injected near the probe).

2.11.1 Frequency and Specifications of Calibration - Calibration includes the measurement of four values:

1. Calibration error - the maximum deviation from actual concentration over the range of the instrument.

2. Measurement response time - the time required for the instrument reading to reach a stable value (i.e., a change less than 1% of span value in 30 s) or the time required to display 95% of a step change in gas concentration (i.e., zero gas to mid-level gas).

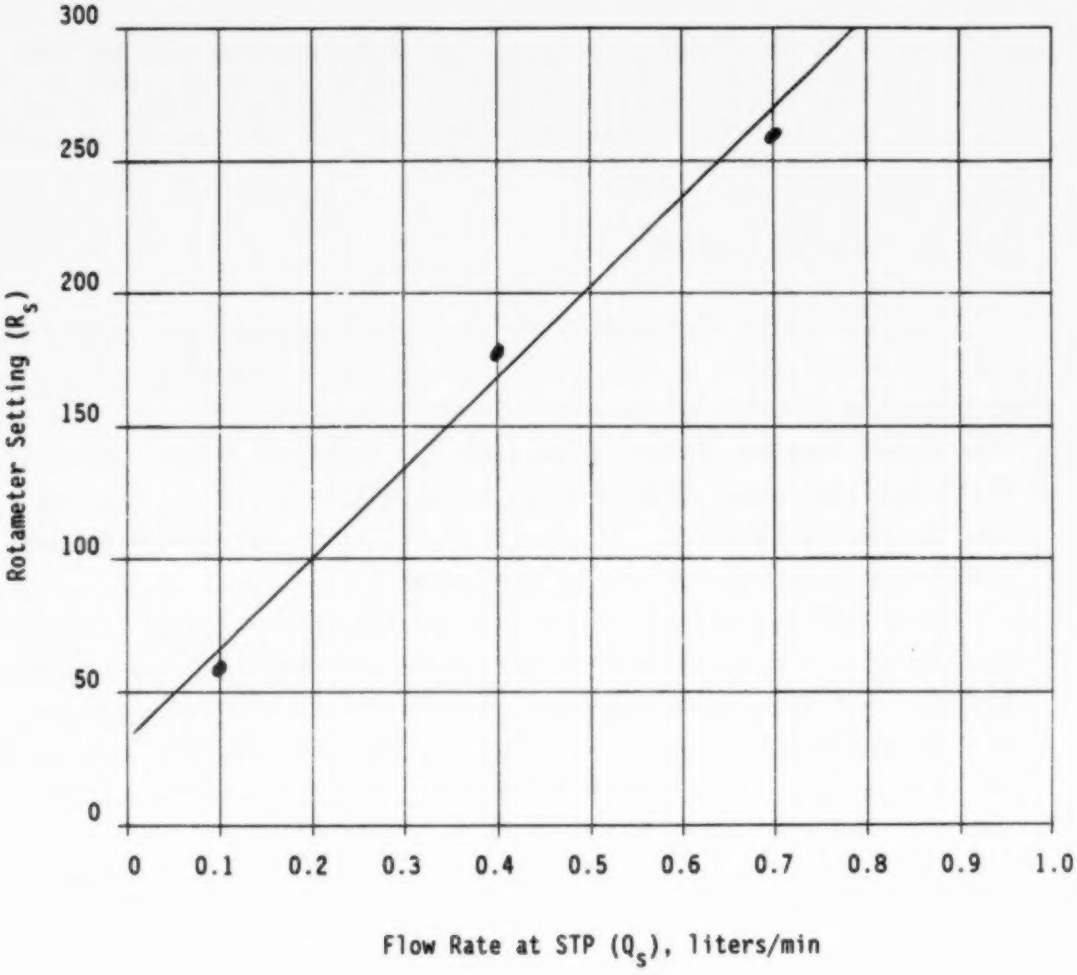


Figure 2.7. Rotameter Calibration Curve

3. Measurement system zero drift - the difference in instrument readings measuring zero gas between pretest and post-test measurements.

4. Measurement system span drift - The difference in instrument readings measuring mid-level calibration gas between pretest and post-test measurements.

Generally, only the calibration error is adjustable. The other parameters can be symptomatic of system problems that will require repair or replacement.

The following matrix summarizes the frequency and specifications for the above parameters:

Measurement	Frequency	Specifications
Calibration error	Within 1 h before starting sampling	Low-level and high-level responses accurate to within 2% of span value
Response time	Before initial use and semiannually	Repeat three times, average should be no more than 2 min
Zero drift	Measure within 1 h before test start and within 1 h after end of test	Less than 2.5% of span value
Span drift	Measure within 1 h before test start and within 1 h after end of test	Less than 2.5% of span value when measured at mid-range value

2.11.2 Method of Calibration - The user should follow the calibration procedures recommended by the manufacturer. This section describes general calibration procedures using an NDIR carbon monoxide analyzer as an example. Specific procedures may differ for some analyzers.

The NDIR and associated apparatus are shown in Figure 2.8; all components are similar to those used in most sampling systems. Prior to leak check and calibration, add new or reconditioned indicating-type silica gel and new Ascarite, if necessary. Then leak check the system by closing the gas cylinder valves and excess flow valve, opening the control needle valve, and turning on the pump. If the rate meter at the NDIR inlet indicates flow, there is a leak. Check all connections and fittings for tightness. After the leak check, open the excess flow valve, shut off the pump, turn on the analyzer power, and allow the analyzer to warm up according to the manufacturer's instructions. Because the NDIR analyzer is temperature sensitive, allow it to warm up $\geq$2 h, preferably overnight. When calibrating an analyzer, follow the manufacturer's instructions for setting the zero and the up-scale span point.

Calibration of NDIR analyzers may be multipoint checks, zero and span checks, or a zero check. Multipoint calibration is used to establish the calibration curve (or relationship) between the analyzer output and the CO input. This type of calibration is performed upon receipt of the analyzer, immediately after maintenance or internal adjustments of the analyzer, and at least semiannually. Zero and span checks establish whether the predetermined calibration has changed during analysis. This type calibration is performed at the start and the end of each test series.

Before entering calibration gases for the pretest calibration, many analyzers should be adjusted electronically. This involves setting the electronic zero and span according to the manufacturer's instructions. If an external recorder is used, the reading should be adjusted to zero after shorting the recorder input terminals together.

2.11.2.1 Multipoint Calibration - A multipoint calibration should be performed upon receipt and before each applicability determination test. The multipoint procedure is used for plotting calibration curves. The following definitions apply:

- High-level gas - 80-90% of span value.
- Mid-level gas - 45-55% of span value.

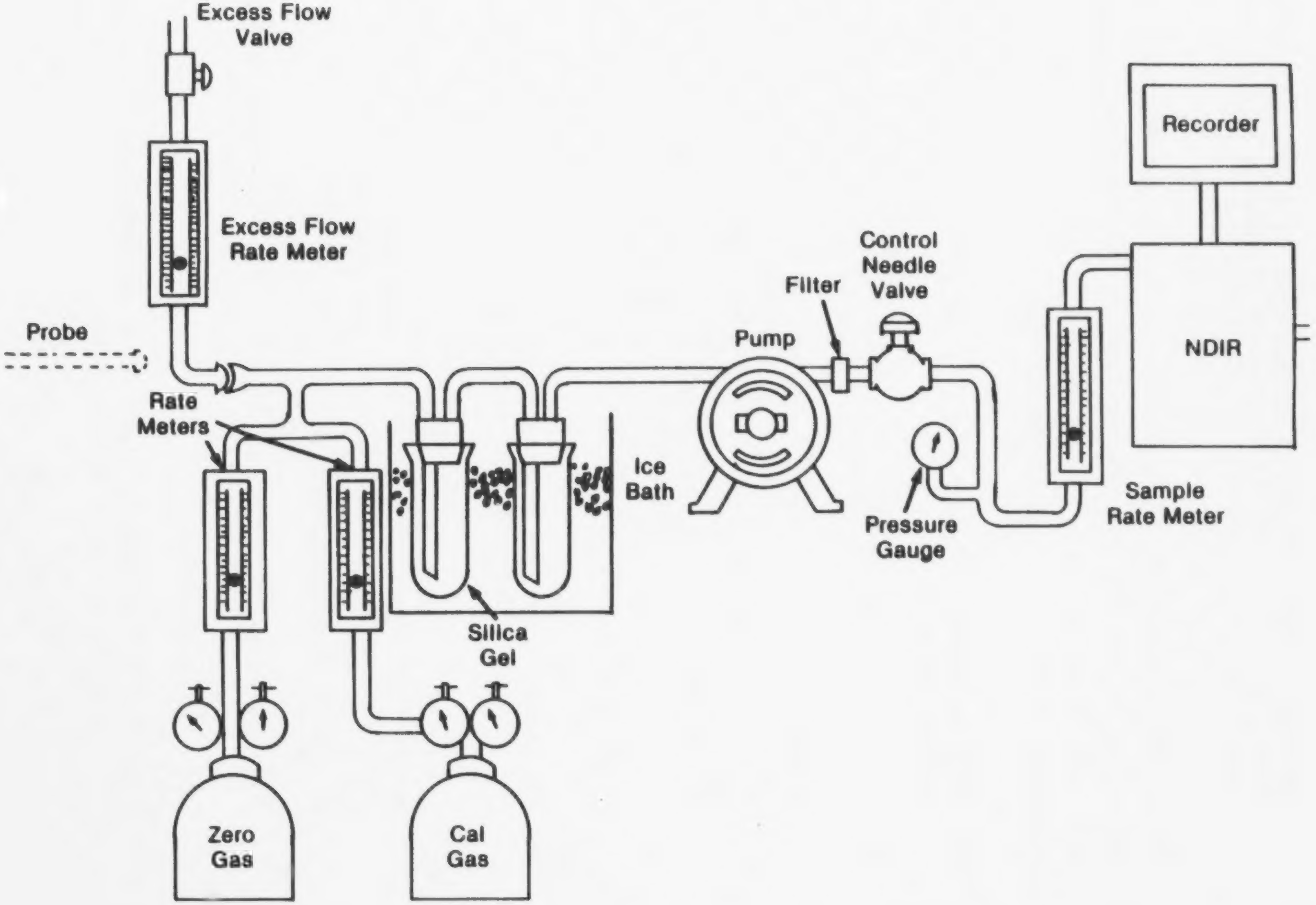

Excess Flow
Valve
Excess Flow
Rate Meter
Probe
Rate
Meters
Zero
Gas
Cal
Gas
Silica
Gel
Ice
Bath
Pump
Filter
Control
Needle
Valve
Pressure
Gauge
Sample
Rate Meter
Recorder
NDIR

Figure 2.8. Example Calibration Setup

- Low-level gas - 20-30% of span value.
- Zero gas - a gas concentration less than 0.25% of the span value. Note: If the analyzer is not capable of reading zero gas, a concentration less than 10% of the span value can be used.

The following multipoint procedures should be followed for each of the analyzers. For the pretest zero and mid-level calibration, only Steps 1 through 11 and 19 are required. Note: Procedures may vary depending on the recommendations of the manufacturer and the sample train configuration used.

1. Open the excess flow valve and the control needle valve, and then turn on the pump.
2. Open the zero gas cylinder valve and adjust the secondary pressure regulator to deliver 10 lb per square inch gauge (10 psig).
3. Adjust the zero gas cylinder control and the control needle valves slowly and simultaneously until the excess flow meter indicates a low rate (to ensure that air is not being pulled back through the excess flow line by the pump) and until the appropriate flow rate is reached at the sample rate meter. Note: Flow rates of 0.5 to 1.0 L/min are normally recommended. Most analyzers are not sensitive to flow rate changes below 1.0 L/min, but the rate established at calibration should be maintained throughout the test series.
4. Set the analyzer zero adjustment by the manufacturer's instructions after a stable reading is established (a minimum of 5 min).
5. Adjust the recorder zero control knob until the trace corresponds to the line representing 5% of the strip chart width above the chart zero or baseline to allow for any negative zero drift. If the strip chart already has an elevated baseline, use the baseline for the zero setting.
6. Mark the strip chart trace at adjusted zero and record the data on a form such as Figure 2.9. Note: Circle the gas analyzed.
7. Turn off the zero gas.
8. Open the mid-level gas cylinder valve and adjust the secondary pressure regulator to deliver 10 psig.

Location ABC Testers Date 3/30/88 Operator J. S.

Analyzer Number CO Range ____ Flow Rate 1.5 lpm Cell Pressure ____

Zero Gas N2 Cylinder Pressure 2000 PSIG Cylinder Number 17647N

High-level Gas 4.0 % Cylinder Pressure 2500 Cylinder Number 15260Z

Mid-level Gas 3.1 % Cylinder Pressure 2250 Cylinder Number 15260A

Low-level Gas 2.0 % Cylinder Pressure 2050 Cylinder Number 15333

Zero Control Setting + 045 Span Control Setting + 068

Recorder Type Bendix Serial Number ____

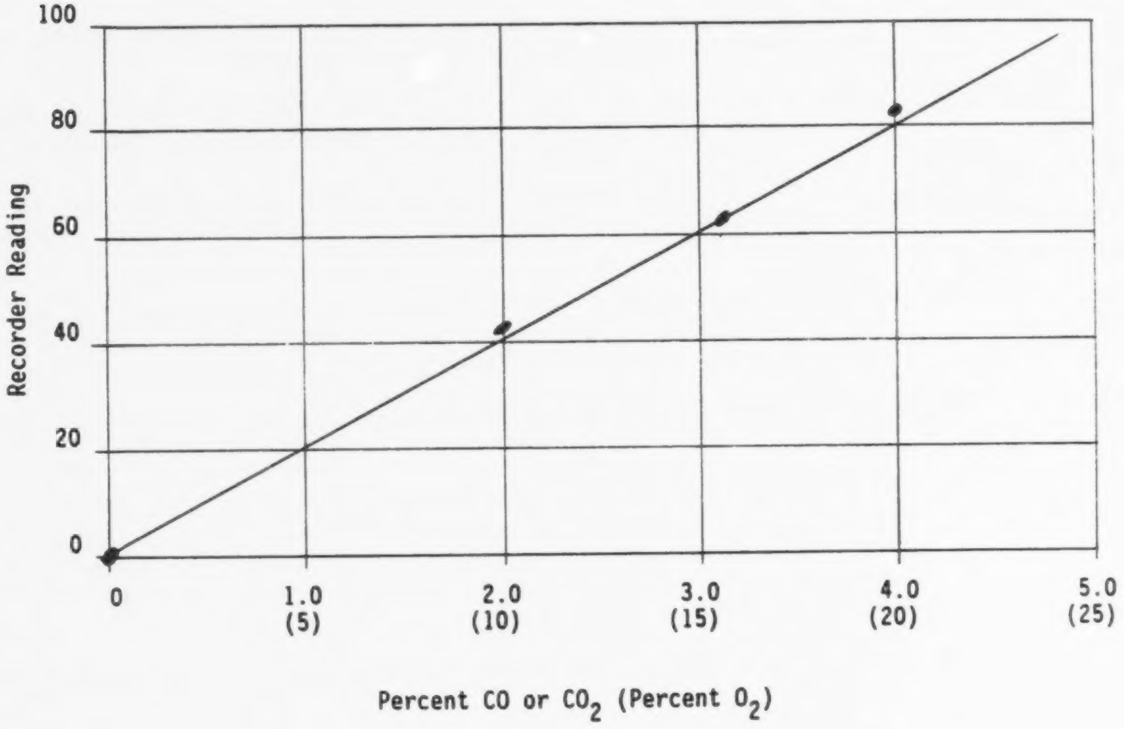


Figure 2.9. Sample Calibration Curve

9. Open the mid-level gas control valve until the excess flow meter indicates a low flow (refer to Step 3).

10. Check the sample rate meter to ensure that the same flow rate used to zero the analyzer is maintained. If not, adjust the flow valves.

11. Set the analyzer span by the manufacturer's instructions after a stable trace is established (a minimum of 5 min). Note: Some analyzers require two or more adjustment cycles of the zero and the high-level setting to get desired readings.

12. Mark the strip chart trace for the adjusted span and record the data on a form such as Figure 2.9.

13. Close the mid-level gas cylinder valve and the control valve, and remove the cylinder from the pressure regulator.

14. Replace the mid-level gas cylinder with the high-level reference gas cylinder that contains about 80-90% of the span concentration.

15. Open the high-level reference gas cylinder valve and adjust the cylinder secondary pressure regulator to deliver 10 psig. Repeat Steps 9 and 10.

16. Allow a stable trace to be established on the recorder. Do not adjust analyzer zero or span control. Mark the strip chart trace and record the data on the form.

17. Repeat Steps 13 through 16 for the low-level 20-30% span concentration.

18. Plot concentration versus percentage relationship (Figure 2.9) after the multipoint calibration is complete. Draw a straight line through the zero point and mid-level points. The low-level and high-level points should be within 2% span from their predicted values.

19. Turn off all gas cylinders and remove the excess flow valve and rate meter assembly.

The analyzer is now ready for sample analysis.

2.11.2.2 Zero and Mid-level Drift Checks - Follow this procedure in conducting the zero and mid-level drift checks within 1 h after the test:

1. Attach the excess flow rate meter and excess flow valve assembly as shown in Figure 2.8.

2. Open the zero gas cylinder valve and adjust the secondary pressure regulator to deliver 10 psig.

3. Adjust the zero gas control and the control needle valves slowly and simultaneously until the excess flow meter indicates a low flow and the sample rate meter reads the same as it did during sampling.

4. Mark the strip chart trace as "unadjusted zero" and record the data on Figure 2.10 after a stable zero trace is established. A stable trace means less than 1% of span change in 30 s.

5. Adjust the analyzer zero to the zero reading established in the multipoint calibration. Mark the strip chart trace as "adjusted zero" and record the value on the form.

6. Turn off the zero gas.

7. Open the high-range calibration gas cylinder valve and adjust the secondary pressure regulator to deliver 10 psig.

8. Open the high-range calibration gas control valve until the excess flow meter indicates a flow.

9. Check the sample rate meter and be sure that the same flow rate used during sampling is maintained. If not, adjust the flow valves.

10. After a stable trace is achieved, label as "unadjusted high-range" and record the value on Figure 2.10.

11. If the unadjusted high-range value (from the calibration curve) differs from the high-range value determined during the multipoint calibration by more than ±2.5% of the span value, readjust the setting. Use Equation 2.1 (for CO) to determine the percentage mid-range difference between the two values.

$$\%\ \text{difference} = \frac{CO_c - CO_s}{CO_{FS}} \times 100 \qquad \text{Equation 2.1}$$

where:

CO_c = concentration of high-range gas,

CO_s = concentration of high-range gas as measured, and
CO_{FS} = full scale of the range on which the gas is measured.

Location ABC Tester Operator J. S.

Analyzer CO Post-test ✓ Pretest X

Date	Gas	Zero		High- or [✓ Mid-range]		Percent Difference
		Unadjusted	Adjusted	Unadjusted	Adjusted	
3/30	zero gas 2.5 %	– 0.005	0.000	2.65	2.50	N/A

Figure 2.10. Calibration Drift Verification Record Chart

TABLE 2.1. ACTIVITY MATRIX: CALIBRATION OF APPARATUS

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Process Measurement Equipment			
Platform scale	±0.05 kg (0.1 lb)	Before first certification test (manufacturer's calibration is acceptable for initial calibration) and before each subsequent certification test - Class F weight	Five-point recalibration
Balance (optional)	±0.05 kg (0.1 lb)	Before each certification test - Class F weight	Recalibrate
Facility temperature monitor	±1.5% absolute	Before first test and semiannually - ASTM thermometer or Method 2	Replace or adjust
Anemometer	Threshold at least 0.1 m/s (20 ft/min)	Before first test and semiannually - per Method 14	Replace or adjust
Barometer	±0.1 in. Hg	Before first test and semiannually - mercury barometer	Replace or adjust
Draft gauge	±0.5 Pa (0.002 in. H_2O) at 1.25 Pa (0.005 in. H_2O)	Before first test and semiannually - liquid manometer	Replace or adjust

TABLE 2.1. ACTIVITY MATRIX: CALIBRATION OF APPARATUS (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Humidity gauge	±3% relative humidity	Before first test and semiannually - wet bulb hygrometer	Replace or adjust
Wood moisture meter	±1% at 19% to 25% moisture (dry basis)	Before each test - resistance method	Replace or adjust
Sample and Analysis Equipment			
Orsat analyzer	Average of three replicate ambient air samples should be 20.8 ± 0.5% (absolute) for O_2 or known concentration ±0.5 (absolute) for calibration gases	Upon receipt and before any test in which the analyzer has not been checked during the previous 3 months, determine $\%O_2$ in ambient air, or use a calibration gas with known CO, CO_2, and O_2 concentrations	Check Orsat analyzer for leaking valves, spent absorbing reagent, and/or operator techniques; take corrective action
Rotameter or other rate meter	Smooth curve of rotameter actual flow rates with no evidence of error greater than 5% of actual flow	Check with wet test meter or reference volume meter at 6-month intervals or at indication of erratic behavior	Clean meter and repeat calibration steps until limits are attained, or replace

TABLE 2.1. ACTIVITY MATRIX: CALIBRATION OF APPARATUS (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
O_2, CO_2, and CO analyzers	Multipoint calibration: 3-point (plus zero) to establish curve of analyzer; calibration at zero and mid-levels must predict low-level and high-level gas concentrations within 5%	Calibrate curve upon receipt immediately after maintenance of internal adjustment	Recalibrate instrument; recheck electronic zero and repeat calibration procedures; repair or replace if problem persists
	Pretest zero and mid-range adjustment	Set zero and mid-range within 1 h before starting test; calibrate by adjusting zero and mid-range to agree with certified gas concentration	Same as above
	Zero and span drift check: <2.5% of full range value	Check zero and mid-range span drift within 1 h following test	Same as above
	Response time: 2 min to reach 95% of a span shift	Measure upon receipt and semiannually	Repair or return instrument to manufacturer

3.0 PRETEST PROCEDURES

In this section, discussion of pretest procedures is organized into three subsections, which include the following activity categories:

- Process operation procedures,
  - Measurement of firebox volume,
  - Wood heater installation,
  - Apparatus check and calibration,
  - Test fuel measurements,
  - Test fuel crib construction,
  - Pretest facility condition measurements,
  - Pretest burn conditions,
- Orsat sampling and analysis pretest procedures,
  - Installation of equipment,
  - Check equipment,
- CEMS sampling and analysis pretest procedures,
  - Installation of equipment, and
  - Calibration of equipment.

An activity matrix summarizing quality assurance activities for pretest procedures is presented in Table 3.1 at the end of this section. Figure 3.11 at the end of this section is a checklist to assist testing personnel in conducting pretest procedures.

3.1 Process Operation Pretest Procedures

3.1.1 Measurement of Usable Firebox Volume - Detailed measurement of the firebox dimensions is required to calculate usable firebox volume. If the usable firebox volume is 1.86 m^3 (20 ft^3) or more, the wood heater is exempt from 40 CFR Part 60, Subpart AAA - Standards of Performance for New Residential Wood Heaters. Otherwise, the usable firebox volume determines the mass of fuel to use during applicability determination testing. It is recommended that the firebox measurements be made upon receipt of the heater, prior to installing it for testing purposes. Since the calculation of usable firebox volume is a critical determination and subject to error, at least two independent determinations should be performed prior to emission testing. If agreement of the independent volume determinations is not within 5%, they should be repeated.

3.1.1.1 Firebox Volume Measurement Definitions - Refer to EPA Method 28 for definitions and guidelines to be followed when making volume measurements. Definitions for height, length, and width are as follows:

1. Height - The vertical distance extending above the loading door, if fuel could reasonably occupy that space, but not more than 0.05 m (2 in.) above the top of the loading door, to the floor of the firebox (i.e., below a grate) if the grate allows a 0.025 m (1 in.) diameter piece of wood to pass through the grate, or, if not, to the top of the grate. Firebox height is not necessarily uniform but must account for variations caused by internal baffles, air channels, or other permanent obstructions.
2. Length - The longest horizontal fire chamber dimension that is parallel to a wall of the chamber.
3. Width - The shortest horizontal fire chamber dimension that is parallel to a wall of the chamber.

3.1.1.2 Firebox Volume Adjustments - Areas inside the firebox where wood cannot reasonably be placed must be excluded from the usable volume determination. Examples of specific adjustments to firebox volume measurements required by Method 28A are summarized below:

1. Volume determinations must be adjusted to exclude space occupied by firebrick or permanent fixtures.
2. Width and length dimensions must be measured above the firebrick lining and extend to the firebox walls, if the firebrick on the walls extends less than one-third of the usable height.

3. Width and length dimensions should be measured to the firebrick, if the firebrick extends more than one-third of the usable height.

4. Areas around the permanent log retainers or grates should be excluded from usable volume determinations, if the manufacturer recommends that wood should be placed only on the retainers or grates.

5. Areas adjacent to and above a baffle (up to 0.05 m or 2 in., above the fuel loading opening) should be included if 0.10 m (4 in.) or more horizontal space exists between the edge of the baffle and a vertical obstruction (e.g., sidewalls or air channels).

6. Areas above an ash lip may not be excluded from the usable volume measurements if these areas make up more than 10% of the adjusted usable firebox volume.

7. If the criterion in Item 6 is not met, areas above the ash lip should be included if testing personnel judge that consumer loading practices would generally use such space. For instance, if fuel is to be loaded front to back, an ash lip may be considered usable firebox volume.

Figure 3.1 is a general example illustrating areas within a firebox that should be excluded when determining usable firebox volume.

3.1.1.3 Firebox Volume Calculations and Documentation - Firebox volume determinations must be documented and recorded. The following step-by-step procedure should be used as a guideline for determining the firebox volume. Using a standard set of procedures such as these will help the testing team obtain accurate measurements and results that can be reproduced by an auditor.

1. Prepare scale drawings showing at least two views of the firebox, detailing critical interior measurements. Figure 3.2 is a general example.

2. Compare measured dimensions against engineering drawings provided by the wood heater manufacturer.

3. Divide interior firebox into usable and unusable firebox volume components based on guidelines presented in Section 3.1.1.2 (above) and Method 28, Section 6.2.4. Figure 3.3 illustrates this firebox volume determination approach.

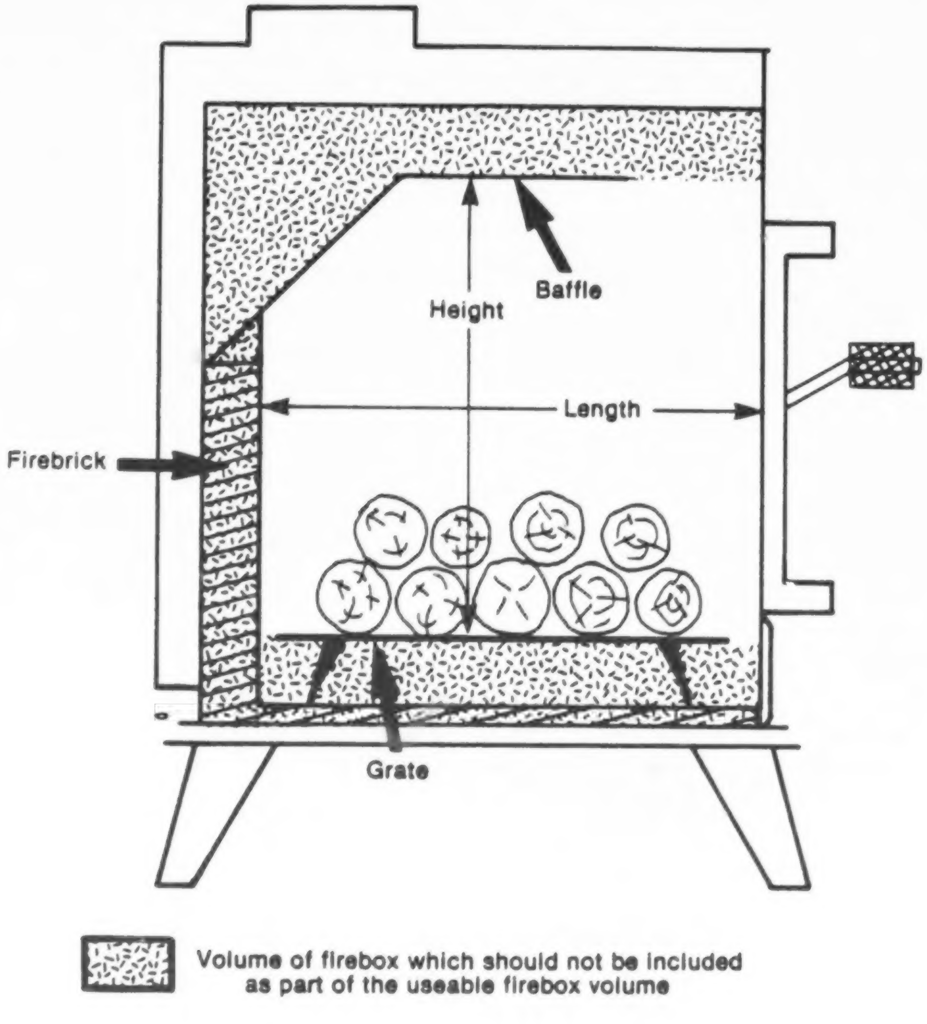

Baffle
Height
Length
Firebrick
Grate
▨ Volume of firebox which should not be included as part of the useable firebox volume

Figure 3.1. Example of Usable Firebox Volume

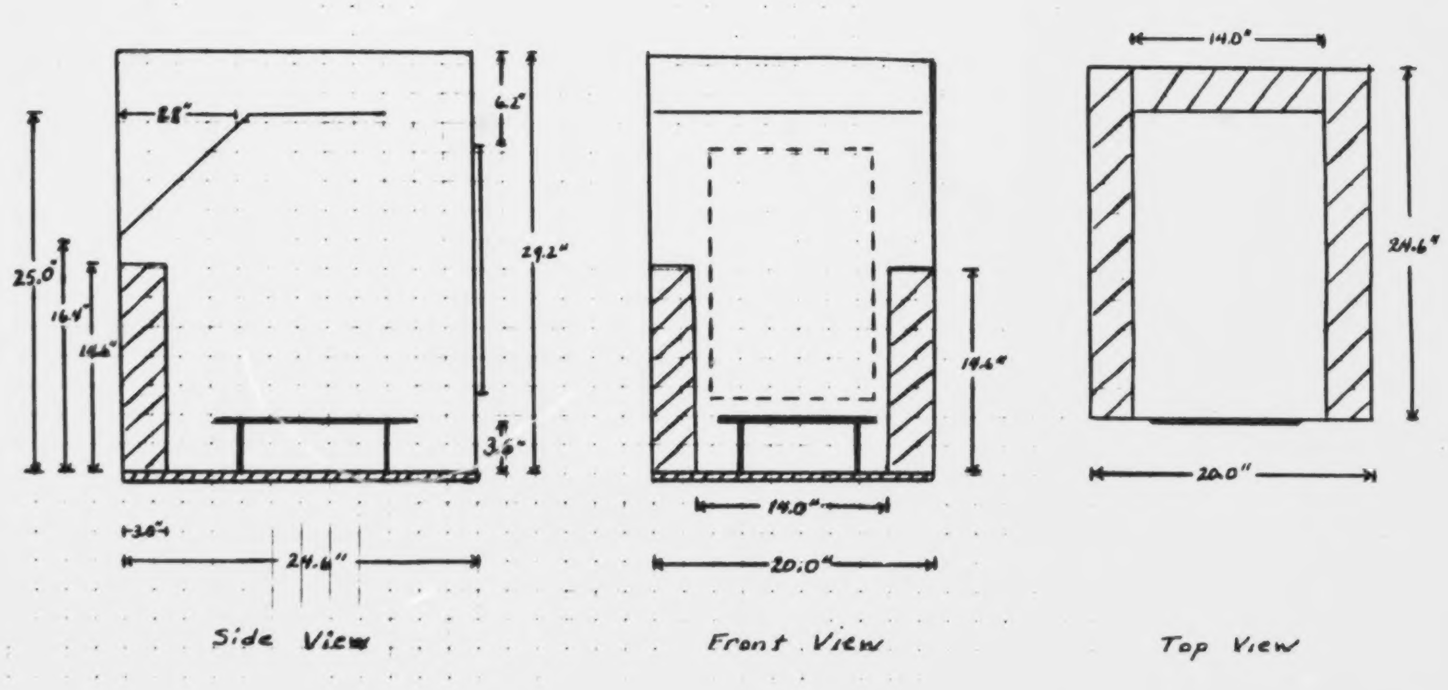

8.8"
6.2"
25.0"
16.4"
14.6"
29.2"
3.6"
3.0"
24.6"
Side View
14.6"
14.0"
20.0"
Front View
14.0"
24.6"
20.0"
Top View

Figure 3.2. Example of Scale Firebox Drawings to Document Usable Volume Determinations

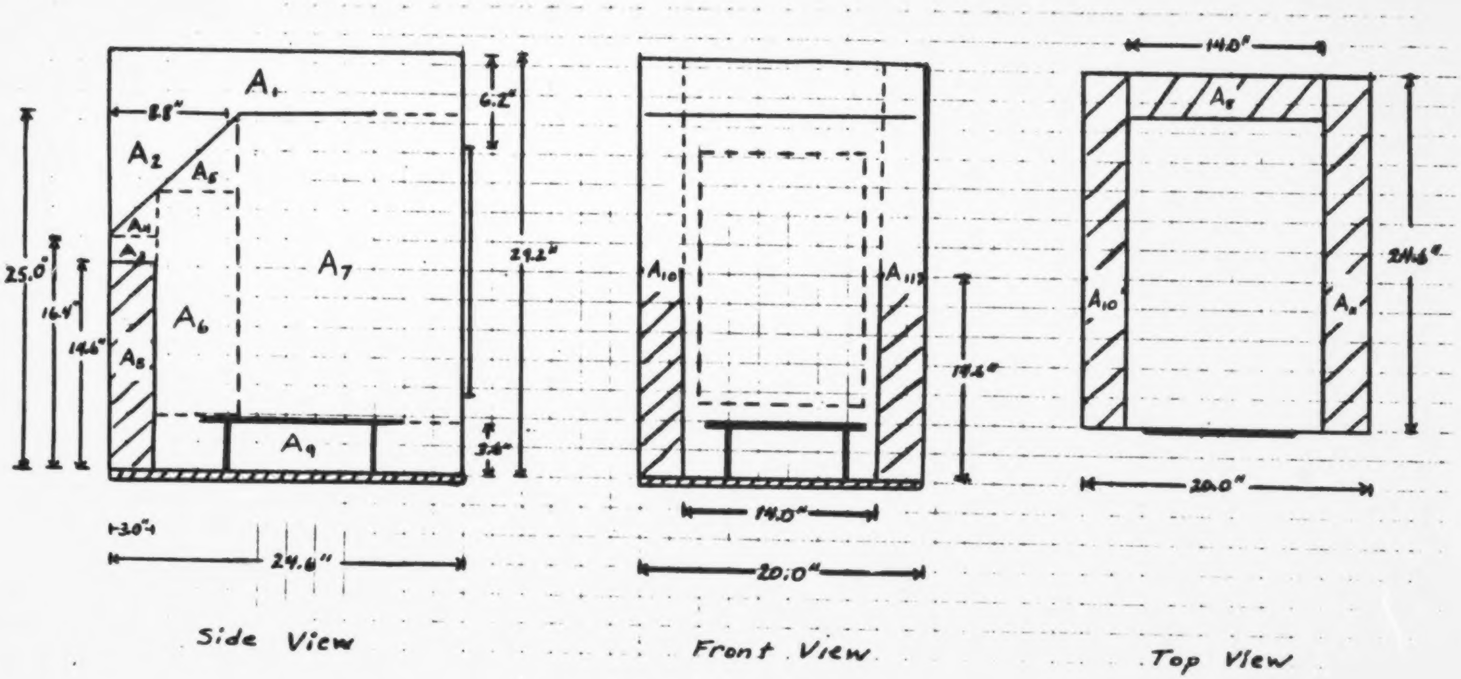

A1
8.8"
6.2"
A2
A5
A4
A3
A7
A6
A8
A9
25.0"
16.4"
14.6"
29.2"
3.6"
3.0"
24.8"
Side View
A10
A11
19.6"
14.0"
20.0"
Front View
14.0"
A8
A10
A11
24.6"
20.0"
Top View

Figure 3.3. Example of Firebox Volume Divided Into Specific Component Volumes

4. Calculate the volume of each of the interior firebox volume components by using basic arithmetic, geometry, and trigonometry. Sketch each of the volume components, show dimensions and calculations, and provide rationale for including or excluding each component as usable volume. Figure 3.4 is an example of this step.

5. Calculate usable firebox volume by summing all usable component volumes as calculated in Step 4. Confirm the calculated usable volume by subtracting the sum of the unusable volume components from the total interior firebox volume (see Figure 3.4).

3.1.2 Wood Heater Installation - Installation of the wood heater follows determination of usable firebox volume. This subsection presents guidelines for installing the wood heater flue pipe and optional liquid seal.

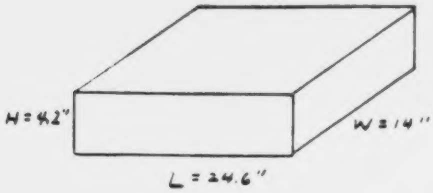
The wood heater should be placed on a platform scale and fitted with a clean, steel flue pipe that extends 2.45 to 2.75 m (8 to 9 ft) above the top of the platform scale. If a heat insulation shield is used between the wood heater and the platform scale, the height should be measured from this surface. An insulated solid pack chimney section is positioned above the steel flue pipe and must extend 4.3 to 4.9 m (14 to 16 ft) above the platform scale. Both the steel flue pipe and ISP should be assembled leak-free and should be of a diameter specified as suitable by the wood heater manufacturer. All flue pipe sampling locations should be identified and port holes cut prior to assembling the flue pipe. Figure 1.2 shows Method 28A sampling port locations and allowable height specifications. Gas sampling ports should be located in the steel flue pipe 2.3 ± 0.3 m (7.5 ± 0.5 ft) from the platform scale surface. The wood heater flue pipe should be installed so that exhaust gases are released into an air space inside the test facility, or into a space freely communicating with the test facility. Hoods or other devices for capturing and venting exhaust gases to the outside are recommended.

Since the required length of ISP chimney sections typically weighs between 23 and 36 kg (50 and 79 lb), this chimney section should be securely attached to the test facility ceiling or walls. Factory-made support

Reproduced from best available copy.

Calculation of Usable Firebox Volume

A₁

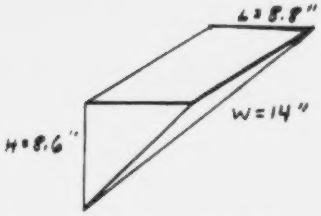


$H = 29.2 - 25.0 = 4.2$
$L = 24.6$
$W = 14$

$V = 4.2 \times 24.6 \times 14 = 1446.5 \text{ in}^3$

A₁ is not included in usable volume since it is above the baffle, and 2 inches above door opening.

A₂

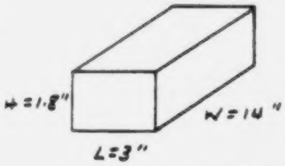


$H = 25.0 - 16.4 = 8.6$
$L = 8.8$
$W = 14$

$V = 1/2(8.8 \times 8.6) \times 14 = 529.8 \text{ in}^3$

A₂ is not included since this space is above the baffle and wood cannot reasonably be placed here.

A₃

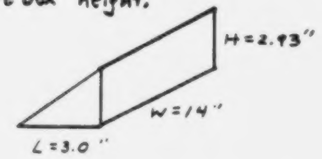


$H = 16.4 - 14.6 = 1.8$
$L = 3.0$
$W = 14$

$V = 1.8 \times 3.0 \times 14 = 75.6 \text{ in}^3$

A₃ is not included because it is directly above the firebrick, which extends more than 1/8 the usable fire box height.

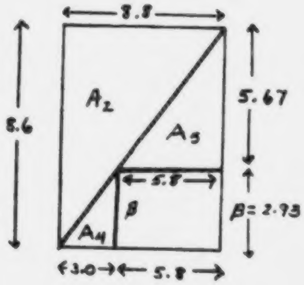
A₄



$H = 2.93$
$L = 3.0$
$W = 14$

$V = 1/2(3 \times 2.93) \times 14 = 61.53 \text{ in}^3$

(see figure to right)



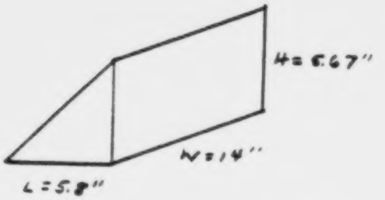
A₄ is not included for the same reason as A₃.

$$\frac{3.0}{8.8} = \frac{\beta}{8.6}$$

$\beta = 2.93$

Figure 3.4. Example Calculation of Specific Firebox Volume (Based on Components Illustrated in Figure 3.3)

A_5



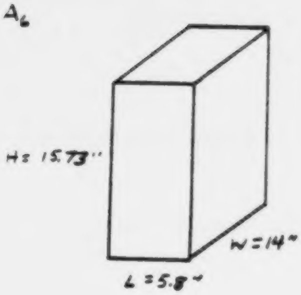
H = 5.67
L = 5.8
W = 14

$V = \frac{1}{2}(5.8 \times 5.67) \times 14 = 230.2 \text{ in}^3$

(see previous figure)

A_5 is included

A_6

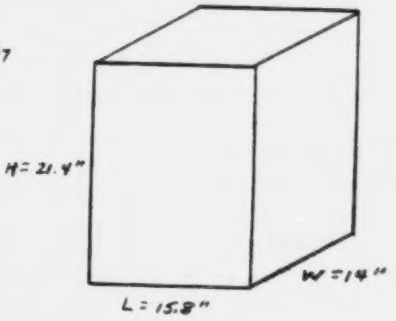


H = (14.6 - 3.6) + 1.8 + 2.93 = 15.73
L = 5.8
W = 14

$V = 15.73 \times 5.8 \times 14 = 1277.3 \text{ in}^3$

A_6 is included

A_7

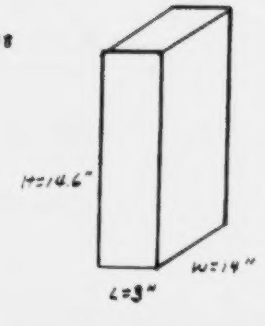


H = 21.4
L = 15.8
W = 14

$V = 21.4 \times 15.8 \times 14 = 4733.7 \text{ in}^3$

A_7 is included

A_8



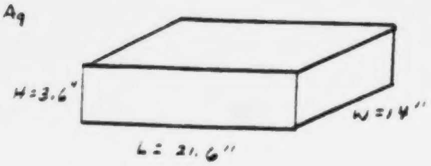
H = 14.6
L = 3.0
W = 14

$V = 14.6 \times 3 \times 14 = 613.2 \text{ in}^3$

A_8 is not included since firebrick is a permanent component.

Figure 3.4. Example Calculation of Specific Firebox Volume (Based on Components Illustrated in Figure 3.3) (Continued)

A_9

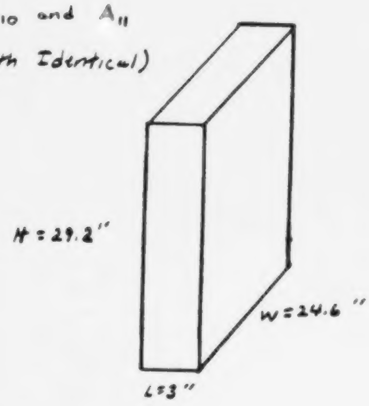


$H = 3.6$
$L = 24.6 - 3.0 = 21.6$
$W = 14$

$V = 3.6 \times 21.6 \times 14 = 1088.6 \text{ in}^3$

A_9 is not included because this space includes the permanent grate and the space under the grate.

A_{10} and A_{11}
(Both Identical)



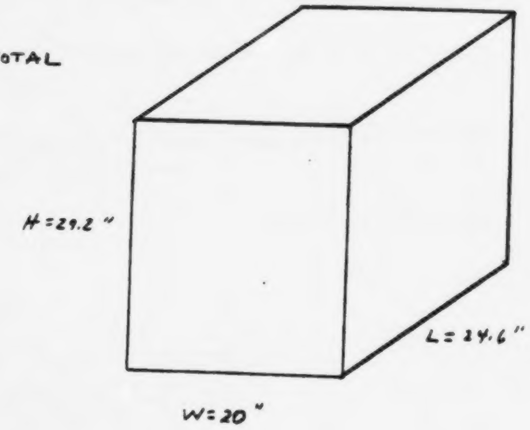
$H = 29.2$
$L = 3.0$
$W = 24.6$

$V_{10} = 29.2 \times 3 \times 24.6 = 2155.0 \text{ in}^3$

$V_{11} = 2155.0 \text{ in}^3$

A_{10} & A_{11} are not included because firebrick is a permanent component.

A_{TOTAL}



$H = 29.2$
$L = 24.6$
$W = 20$

$V_T = 29.2 \times 24.6 \times 20 = 14366.4 \text{ in}^3$

Figure 3.4. Example Calculation of Specific Firebox Volume (Based on Components Illustrated in Figure 3.3) (Continued)

Firebox Volume is Calculated 2 ways:

1st method

Usable firebox Volume = sum of usable components

$$\text{Usable firebox Volume} = A_5 + A_6 + A_7$$

$$= 230.2 + 1277.3 + 4733.7$$

$$= 6241.2 \text{ in}^3$$

$$= 6241.2 \text{ in}^3 \times \frac{1 \text{ ft}^3}{(12)^3 \text{ in}^3}$$

$$= 3.61 \text{ ft}^3$$

2nd method (check)

Usable firebox Volume = Total Volume − Unusable Volume

$$\text{Usable firebox Volume} = A_{Total} - (A_1 + A_2 + A_3 + A_4 + A_8 + A_9 + A_{10} + A_{11})$$

$$= 14{,}366.4 - (1446.5 + 529.8 + 75.6 + 61.53 + 613.2 + 1088.6 + 2155 + 2155)$$

$$= 14366.4 - 8{,}125.2$$

$$= 6241.2 \text{ in}^3$$

$$= 3.61 \text{ ft}^3$$

Figure 3.4. Example Calculation of Specific Firebox Volume (Based on Components Illustrated in Figure 3.3) (Continued)

assemblies are commercially available and may be used in suspending the ISP. Assemblies used for securing ISP sections should allow vertical movement of the flue so that the distance between the flue pipe exhaust and venting or dilution tunnel hood may be adjusted. Solid support of the ISP section requires that a liquid seal or similar device be installed in the flue pipe to allow vertical movement of the platform scale.

3.1.3 Liquid Seal and Adapter Sections - A liquid seal is illustrated in Figure 1.3. This seal or a similar airtight, frictionless connection is necessary for unobstructed scale platform movement if the ISP is solidly supported. If desired, the upper section of the liquid seal can mount directly onto the ISP or it can attach to a steel pipe connection piece. The seal should be filled to a predetermined level with an oil that has a boiling point greater than 177°C (350°F), and the volume of oil should be checked before and after each test run. The liquid seal should be installed about 0.6 m (2 ft) from the wood heater exhaust flange. Sampling ports should be above the liquid seal section.

3.1.4 Apparatus Check and Calibration - This subsection describes checks and calibrations to be performed prior to the pretest burn period. Although only two of the process operation measurement instruments require pretest calibration (i.e., platform scale and moisture meter), visual and functional checks should be performed on all measurement instruments before beginning pretest burn procedures.

3.1.4.1 Process (Wood Heater Operation) Measurement Apparatus Check - Process measurement apparatus includes a platform scale for determining burn rate and a draft gauge for recording the static pressure in the flue pipe during a test run. Calibration procedures are discussed in Section 2.0 of this manual.

The scale calibration should be checked with a single-point audit before each test begins. To ensure quality data, this single-point calibration check should also be performed after each test run. Platform scale calibration checks should be performed at temperatures commonly encountered during emission testing since the accuracy of some scales is known to be affected by temperature.

The draft gauge (manometer) should be checked for proper fluid level (if liquid type) or battery condition (if battery operated). If the induced draft reading is 0.0 or below the limit of detection, the gauge may be inoperative. Operation can be verified by increasing the exhaust system flow or by decreasing the distance between the ISP and the hood until a reading is obtained, or by placing the gauge in front of a fan.

3.1.4.2 Test Fuel Measurement Apparatus Check - The moisture meter must be calibrated before each test run. The recommended calibration procedure is described in Section 2.8 of this manual. Since wood temperature is an important factor in determining moisture content, the test fuel temperature measurement (i.e., verification of the temperature control system in the test fuel storage area) should be made before the moisture content is determined.

If a separate balance is used to weigh the test crib, its calibration can be checked with the Class F weight used for the platform scale calibration (see Section 2.1).

3.1.4.3 Test Facility Condition Measurement Apparatus Check - The test facility temperature monitor should be operational. The relative humidity gauge (hygrometer) should be checked for proper water level (wet bulb type). The air pressure gauge (barometer) should be checked against a local weather station reading and adjusted for altitude differences between the station and the test facility. To correct for altitude, subtract 2.5 mm Hg/30 m (0.1 in. Hg/100 ft) from the station value for an elevation increase, or add the same for an elevation decrease.

3.1.5 Test Fuel Measurements -

3.1.5.1 Moisture Content - The moisture content of the test fuel must be measured within 4 h before the test run. The moisture meter should be stored with the fuel so that it is at the same temperature. Each piece of fuel (not including spacers) must be measured on three sides (not ends). Moisture readings should be taken at locations on the test fuel pieces that have relatively straight grain and are free of defects. The moisture meter electrodes should be aligned with the grain of the wood and inserted 1/4 of wood depth or 2.5 cm (1 in.), whichever is greater. Especially at higher moisture content levels, the readings should be taken as soon as possible after the electrodes are driven in, since some direct current meters can show a drift toward lower moisture readings after voltage is applied.

For each piece, the three readings are averaged to determine the moisture content per fuel piece. The moisture content of all fuel pieces is averaged to give the test crib moisture content. As an alternative to averaging the moisture content of all fuel pieces, each piece can be weighed and the moisture content of the test fuel load can be determined on a piece-weighted basis. Figure 3.5 shows an example form for documenting and calculating average wood moisture. Adjust the final figure for wood temperature (if required per moisture meter instructions) and convert to wet basis if the meter readings are determined on a dry basis. Wood moisture cannot be measured with confidence with a resistance meter when the moisture content is over 25 to 27% on a dry basis. Therefore, the averages may not accurately represent the sample if any single reading exceeds 25% moisture content (dry basis).

3.1.5.2 Test Fuel Temperature - The test fuel temperature must be known in order to get an accurate moisture content reading. The only reliable way to get the wood temperature is to measure the temperature at which the wood has been stored for 24 h. Test fuel temperature should be recorded with the moisture content measurement as shown in Figure 3.5.

3.1.5.3 Test Fuel Density - Because the density of the test fuel may have the potential to affect emissions, measurement of the wood density is suggested to identify unusually light or heavy test fuel pieces. These pieces should not be used for a test run, although they can be used for pretest burns.

1.0 Wood Heater Test Fuel Information

Wood Heater Manufacturer FakeFire Inc.
Wood Heater Model InserT 1000
Run Number 1
Date 3/30/88

2.0 Pretest Fuel Measurements

Piece	Length (inches)	Dimension (e.g. 4 × 4)	Moisture Meter Readings (% Moisture Dry Basis)			Average % Moisture	Corrected Average*
1	12	4x4	22	21	21	21 33	N/A
2	12	4x4	23	22	24	23 00	
3	13	4x4	26	24	24	24.66	
4	10	4x4	23	23	22	22.66	
5	5	2x4	20	18	20	19 33	
6	6	2x4	21	22	22	21.66	
7	5	2x4	20	21	21	20.00	
8	8	2x4	18	19	20	19 00	
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

* Corrected for Moisture Meter Pin Type and Test Fuel Temperature

Figure 3.5. Documentation of Test Fuel Measurements

Reproduced from best available copy.

3.0 Test Fuel Measurements

Piece	Length (inches)	Dimension (e.g. 4 × 4)	Moisture Meter Readings (% Moisture Dry Basis)			Average % Moisture	Corrected Average*
1	20	4x4	20	19	20	19.66	N/A
2	"	"	21	19	20	20.00	
3	"	"	22	21	21	21.33	
4	"	"	20	21	20	20.33	
5	21	2x4	20	21	21	21.66	
6	"	"	23	22	23	22.66	
7	20	"	22	22	23	22.33	
8	"	"	24	23	23	23.33	
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

* Corrected for Moisture Meter Pin Type and Test Fuel Temperature

Average = 21.41 % MC dry basis

Test Fuel Temperature 70° F

Correction Factor for Pin Type, and Fuel Temperature 1:1 (1.0)

Clock Time of Moisture Readings 6:00 AM

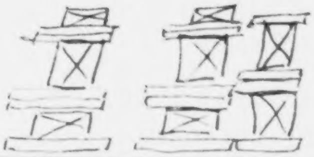
(= 17.63 % MC wet basis)

4.0 Test Fuel Crib

Weight of Test Charge 25.3 (lbs)

Number of Spacers 28

Diagram of Test Fuel Crib



5.0 Conversion to Wet Basis MC

$$\%WB = \frac{100 \times \%DB}{100 + \%DB}$$

%WB = percent moisture content, wet basis

%DB = percent moisture content, dry basis

Figure 3.5. Documentation of Test Fuel Measurements (Continued)

To determine the wood density, divide the weight of a test fuel piece (e.g., an 18-in. dimensional 4 x 4) by the calculated volume (18 in. x 3 1/2 in. x 3 1/2 in. = 220.5 in.^{3}). Douglas fir typically weighs 28 to 38 lb/ft^3 at the allowed moisture content. It is recommended that the test fuel density be recorded with the test results.

3.1.6 Test Fuel Crib Construction - Construction of the test fuel crib is important because the quantity of fuel burned and the arrangement of the test fuel pieces affect emissions sampling. In order to eliminate variations in test fuel loading practices, Method 28A provides specifications for building the test fuel crib. Building the test fuel crib consists of selecting the proper fuel dimensions, determining the test fuel charge density, and arranging the test fuel pieces. Each of these three activities is discussed in this section.

3.1.6.1 Fuel Dimensions - The dimensions of the test fuel pieces should conform to the nominal measurements of 2 x 4 and 4 x 4 lumber. The length of the test fuel pieces should be approximately 5/6 the dimensions of the length of the usable firebox (see Sec. 3.1.1.1 for definition of length). For the firebox shown in Figure 3.2, the length of the usable firebox is 21.6 in. Therefore, the length of the test fuel pieces should be approximately 18 in. (5/6 x 21.6 in.). The proper fuel dimensions (2 x 4 versus 4 x 4) should be determined in relation to the appliance firebox volume according to the guidelines listed below:

- If the usable firebox volume is less than or equal to 0.043 m^3 (1.5 ft^3), use 2 x 4 lumber.
- If the usable firebox volume is greater than 0.043 m^3 (1.5 ft^3) and less than or equal to 0.085 m^3 (3.0 ft^3), use 2 x 4 and 4 x 4 lumber. About half the weight of the test fuel charge should be 2 x 4 lumber, and the remainder should be 4 x 4 lumber.
- If the usable firebox volume is greater than 0.085 m^3 (3.0 ft^3), use 4 x 4 lumber.

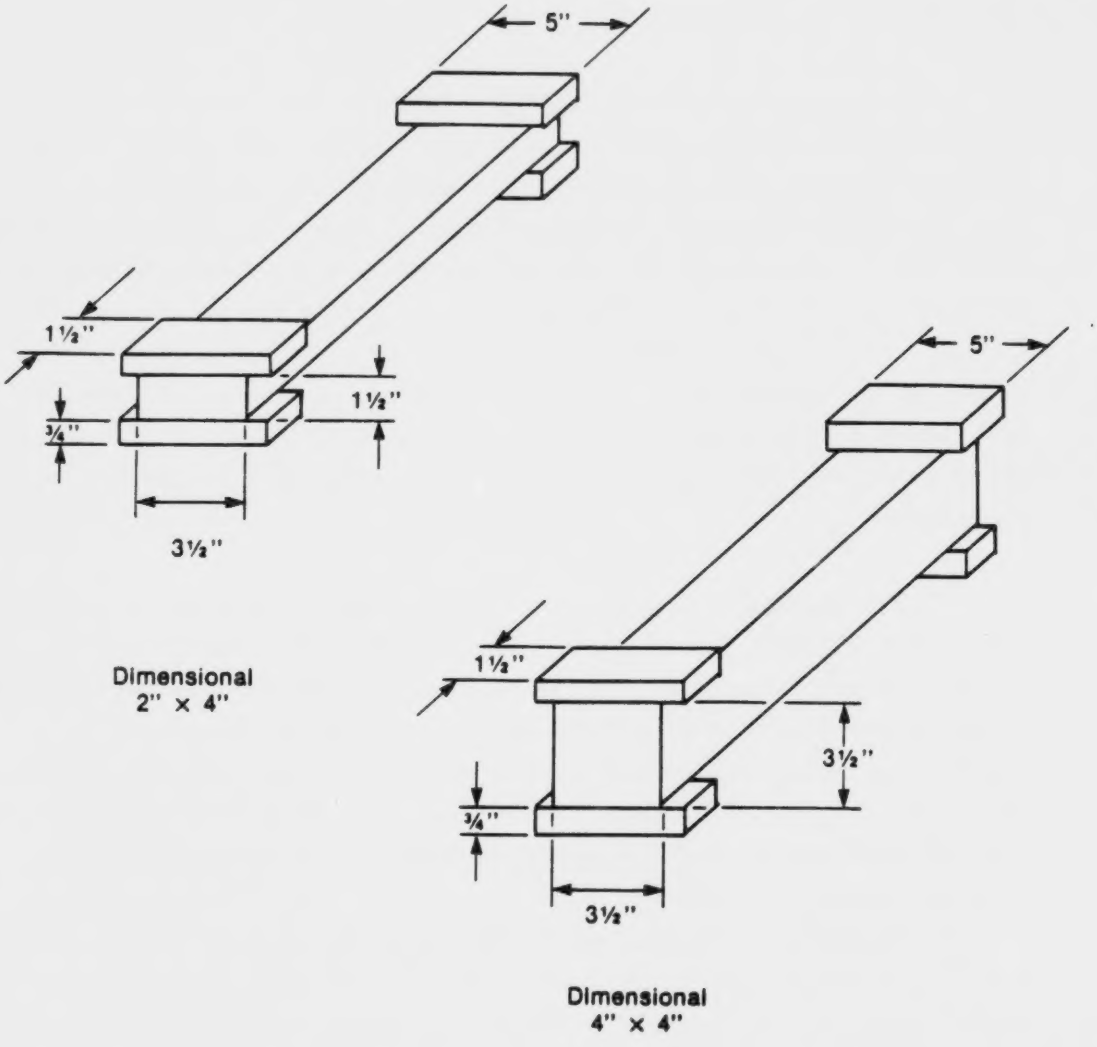
In addition to the test fuel pieces, test fuel spacers constructed of air-dried Douglas fir lumber are also required. The spacers should be 130 x 40 x 20 mm (5 x 1.5 x 0.75 in.).

3.1.6.2 Test Fuel Charge Density - The test fuel charge density is defined as the wet basis weight of the test fuel per unit volume of usable firebox. The test fuel charge density should be 112 ± 11.2 kg/m^3 (7 ± 0.7 lb/ft^3) of usable firebox volume. To determine the weight (in lb) of test fuel required for each load, first measure the usable firebox volume (refer to Section 3.1), and then multiply the usable firebox volume (ft^3) by 7 ± 0.7 lb/ft^3. For the example shown in Figure 3.2, the usable firebox volume was calculated to be 3.61 ft^3. Therefore, the weight of the test fuel charge should be 25.3 ± 2.53 lb, that is, 3.61 ft^3 x (7 ± 0.7 lb/ft^3). The weight of the test fuel charge should include both the test fuel pieces and spacers.

3.1.6.3 Crib Arrangement - The crib arrangement consists of the test fuel pieces and test fuel spacers. Once the test fuel pieces have been cut to their proper dimensions, the spacers should be attached to the test fuel pieces with uncoated, ungalvanized nails or staples as illustrated in Figure 3.6. When stacking difficulties are encountered, all piece lengths should be adjusted uniformly to remain within the specified loading density. The test fuel pieces should be arranged geometrically to conform to the shape of the firebox volume.

If the usable firebox volume is between 0.043 and 0.085 m^3 (1.5 and 3.0 ft^3), alternate the piece sizes in vertical stacking layers to the extent possible. For example, place 2 x 4s on the bottom layer in direct contact with the coal bed and 4 x 4s on the next layer, etc. (see Figure 3.7).

When loading test fuel in wood heaters having unusual or unconventional firebox designs, maintain air space intervals between the test fuel pieces and follow the manufacturer's instructions.


5"
1½"
1½"
¾"
3½"
5"
1½"
3½"
¾"
3½"

Dimensional
2" × 4"

Dimensional
4" × 4"

Figure 3.6. Dimensions of Test Fuel Pieces and Spacers

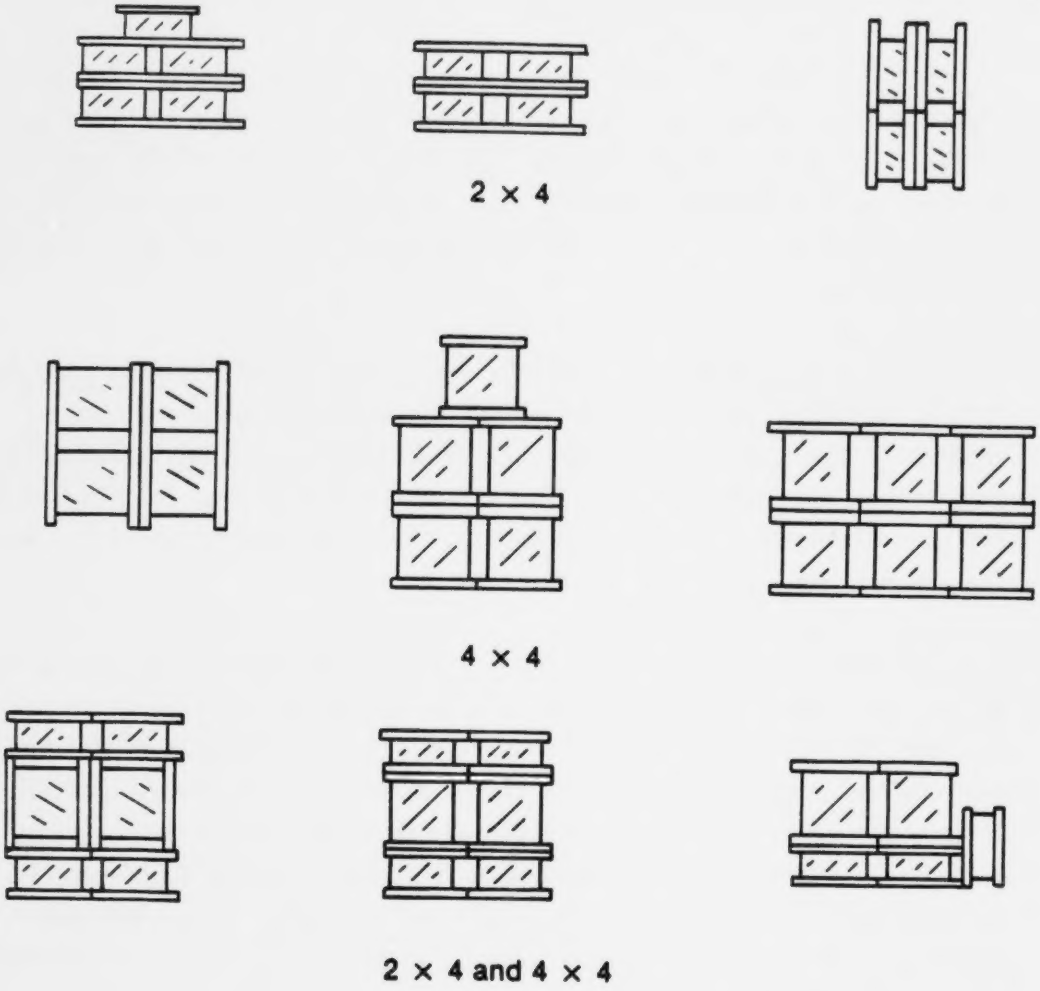

2 × 4
4 × 4
2 × 4 and 4 × 4

Figure 3.7. Test Fuel Crib Arrangements

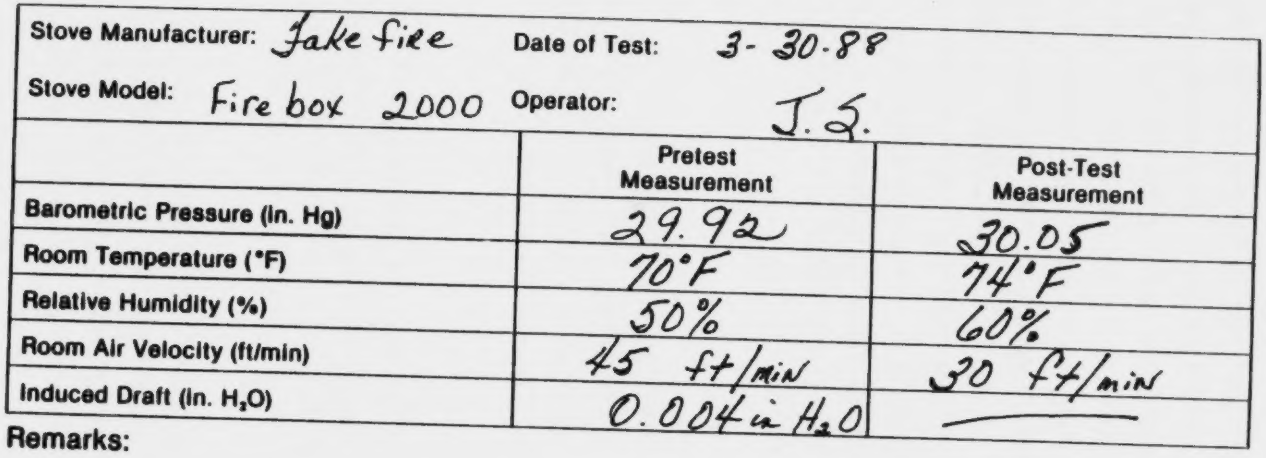
3.1.7 Pretest Facility Condition Measurement - Prior to igniting the pretest fuel charge, various facility conditions must be measured and recorded. Report pretest facility conditions as shown on Figure 3.8.

3.1.7.1 Induced Draft - Induced draft is the suction on the wood heater exhaust gases caused by the dilution tunnel or test facility venting system. The induced draft must be less than 1.25 Pa (0.005 in. H_2O) when measured by a manometer fitted to the flue pipe no more than 0.3 m (1 ft) from the wood heater. Record the induced draft measurement on a test run data sheet such as Figure 3.8.

3.1.7.2 Air Velocity - Air velocity in the vicinity of the wood heater must be measured immediately before the pretest burn ignition. The anemometer should be placed horizontally at several locations around the wood heater and flue pipe. Airflow within 0.6 m (2 ft) of the wood heater and uninsulated flue pipe should be less than 0.25 m/s (50 ft/min). Record the maximum measured air velocity.

3.1.7.3 Air Temperature - The air temperature monitoring device must be located approximately 1 to 2 m (3 to 6 ft) centrally in front of the primary air inlet, as shown in Figure 1.4. The cylindrical shield should be oriented vertically and supported at the same height as the wood heater's primary air inlet. Air should be allowed to flow freely through the cylindrical shield. An air temperature between 18 and 32^{o}C (65 and 90^{o}F) must be maintained throughout the test run. Periodic measurements are required to document that this criterion is met. Test facility temperature should be recorded.

3.1.7.4 Barometric Pressure and Relative Humidity - Measure the barometric pressure and the relative humidity in the test facility area just before beginning the test burn. Note: If the air pressure at the facility is controlled, the air pressure should be monitored and recorded every 10 min during the test. The barometric pressure must not exceed 1033 mbar (30.5 in. Hg) during a test.



Stove Manufacturer: Fake fire Date of Test: 3-30-88

Stove Model: Fire box 2000 Operator: J. S.

	Pretest Measurement	Post-Test Measurement
Barometric Pressure (in. Hg)	29.92	30.05
Room Temperature (°F)	70°F	74°F
Relative Humidity (%)	50%	60%
Room Air Velocity (ft/min)	45 ft/min	30 ft/min
Induced Draft (in. H_2O)	0.004 in H_2O	—

Remarks:

Figure 3.8. Measurement of Test Facility Conditions

3.1.8 Pretest Burn Conditions - The purpose of the pretest burn is to bring the wood heater up to a normal operating temperature, to achieve the desired burn rate, and to produce a sufficient coal bed to ignite and sustain combustion of the test fuel charge during sampling. The uniform coal bed, combustion temperatures, and draft conditions created during the pretest burn procedures are important to the quality of the emission measurements. While the pretest fuel charge is burning, wood heater adjustments are permitted in order to achieve the desired burn rate for the test run. This subsection describes the sequence of activities ranging from the ignition of the pretest fuel charge to the start of the test run. Before starting the pretest burn, the operator should ensure that all adjustments or modifications have been made that are necessary to achieve burn rate category 1 or the lowest achievable burn rate, whichever is greater.

3.1.8.1 Pretest Fuel Charge -

Fuel Requirements - The pretest fuel must meet the same fuel requirements as the test fuel with the following exceptions: the length of each pretest fuel piece should be no less than 1/3 the length of the test fuel pieces, and fuel spacers are not required during the pretest fuel period.

Ignition of the Pretest Fuel - A bed of crumpled newspaper and kindling may be used to help start the fire. Once the fire has been started, the pretest fuel pieces should be placed in the firebox chamber. A crib arrangement resembling the test fuel crib is not required.

3.1.8.2 Pretest Wood Heater Operation and Adjustments - During combustion of the pretest fuel, air supply controls and wood heater auxiliary equipment should be adjusted to achieve the desired burn rate. Figure 3.9 summarizes the types of adjustments that are permitted during the pretest burn and when they should be performed.

Operation	Time of Operation	Action Checklist
1. Ignite pretest fuel	After test fuel charge has been prepared and sampling trains are prepared	______
2. Set the air inlet supply controls at any position that will maintain combustion of the pretest fuel	After ignition of the pretest fuel	______
3. Set the air inlet supply controls at the approximate positions necessary to achieve the lowest possible burn rate	At least 1 h prior to the start of the the test run	______
4. If burn rate is greater than 0.80 kg/m, seal air inlets and close flue damper according to guidelines in Section 3.1.8.2 of this manual.	Some modifications may have to be performed before the pretest burn	______
5. Make any final inlet supply control or fuel adjustments	Up to 15 min prior to start of the test run	______
6. Remove pretest fuel if necessary to adjust the coal bed weight and achieve uniform charcoalization	Up to 15 min prior to start of the test run	______
7. Rake the coal bed to a uniform height	Allowed any time	______
8. Start test run	When the weight of the remaining pretest fuel is between 20 and 25% of the weight of the test fuel charge (and no adjustments, excluding coal bed rakings, were made in the last 15 min)	______
9. Begin sampling and record all initial sampling measurement values	Immediately following the start of the test run	______
10. Load test fuel charge and record test fuel charge weight	Within 1 min of starting the test run	______

Figure 3.9. Summary of Adjustments and Activities During Pretest Burn Procedures

Initially, the air supply controls should be set to any position that will maintain combustion of the pretest fuel. Also, the auxiliary equipment (e.g., blowers, grates) should be operated according to the manufacturer's instructions. After ignition of the pretest fuel has been established, all air supply settings should be "fine-tuned" to the position necessary to achieve a burn rate less than 0.8 kg/h. This burn rate should be maintained for at least 1 h before the start of the test run.

If a burn rate below 0.8 kg/h cannot be attained, the operator must ensure that the lowest possible burn rate is achieved. The following guidelines may be used:

- Remove air setting stops if this can be easily done with household tools.
- Seal air inlets with aluminum tape or other material only if they are not visible after normal installation of the wood heater.
- Make any adjustments that increase the tightness of the door fittings.
- Seal or block off any auxiliary, secondary, or outside air feed ducts if this can be easily done with household tools and if the aesthetic or functional properties of the wood heater are not impaired.
- If the wood heater is equipped with a flue pipe damper, or if one is recommended or suggested by the manufacturer, close the flue pipe damper until there is a reasonable margin before the point that forces smoke into the room.

As a further guideline, the operator should ask what are the reasonable modifications that would make the wood heater burn overnight. A reasonable modification would be one suggested by the owner's manual, easily performed by an owner "handy with tools," and that would not adversely affect the aesthetics of the wood heater. It is not intended that an appliance designed to be operated as fireplaces be transformed into a wood heater for compliance purposes only.

Although there is no limit to the number of air adjustments that may be performed, none is permitted between 15 min before and the start of the test run. Adjustments to the pretest fuel--such as breaking up or removing large pieces of wood--may be necessary to achieve a uniform coal bed. Fuel adjustments are permitted up until 15 min prior to the start of the test run. The coal bed should then be raked to a uniform level just prior to adding the test fuel. Finally, the test run procedures in Section 4.0 should be reviewed and the test run can begin.

3.2 Orsat Sampling and Analysis Pretest Procedures

This section describes the pretest procedures required if the Orsat analyzer sampling option is chosen. The quality assurance activities for presampling operations are summarized in Table 3.1 at the end of this section. Figure 3.11, at the end of this section, or a similar form is recommended to aid the tester in preparing an equipment checklist and status report form.

3.2.1 Equipment Installation - Set up the sampling system as shown in Figure 1.6. Visually check for leaks.

1. Be sure the sampling point in the duct is either at the centroid of the flue pipe and at a point 2.3 + 0.3 m (7.5 ± 0.5 ft) from the scale platform.
2. Place the probe securely in the stack at the sampling point.
3. Seal the sampling port as well as possible with a sponge or rag to prevent dilution of the stack gas by ambient air.
4. Evacuate the flexible bag. Leak check the sampling system by attaching a vacuum gauge to the condenser inlet, drawing a vacuum of 250 mm (10 in.) Hg, and plugging the outlet fitting where the bag is usually attached. Turn off the pump and observe the vacuum reading for 30 s; it should remain stable. If the vacuum drops, check the system for leaks, then repair if necessary, and finally recheck. (These leak checks are optional, but highly recommended.)
5. During the pretest burn period, connect the probe, open the quick disconnect at the bag connection, and purge the sampling system with stack gas by running the pump for about 1 min at a high rate. Make sure that the condenser drain valve is closed tightly.

6. Set the flow rate for each flexible bag outlet at a rate such that about 30 L (1.0 ft^3) will be collected in each bag over the expected duration of the test. For example, the expected test duration is 4 h = 240 min; 30 L/240 min = 0.125 L/min = 0.0042 ft^3/min. Set each rotameter to read about 0.125 L/min (0.0042 ft^3/min).

3.2.2 Equipment Check -

3.2.2.1 Integrated Sample Train - The integrated gas sampling train (Figure 1.6) should be checked before each test as follows:

1. Clean the probe with soap and water, rinse it with water, and allow it to dry. Visually check it for leaks indicated by cracks or corrosion. Cap both ends of the probe tightly to prevent contaminants from entering it while is is not in use. Insert a plug of glass wool into the sampling end of the probe if an external filter is not used.
2. Clean the condenser and leak check it by slightly pressurizing the unit, applying soap to joints and connections, and watching for bubbles.
3. Disassemble, clean, and reassemble the needle valve and rate meter at any sign of foreign matter in the rotameter or erratic behavior of the rotameter.
4. Check the pump for proper operation. Leak check the sample train by plugging the ends, slightly pressurizing the system, applying soap solution to the connections and joints, and watching for bubbles.
5. Leak check the flexible bag by pressurizing and by observing for any loss in pressure as described in Section 1.5.1.6.

3.2.2.2 Orsat Gas Analyzer - The Orsat apparatus should be checked and serviced before each field test in the following manner:

1. Check the confining fluid levels in the leveling bottle and the burette. Be sure the approximately 300 mL of fluid in the leveling bottle is clear, orange, and sufficient to fill the burette. Be sure the solution in the leveling bottle is distilled water containing approximately 5% by volume of concentrated

sulfuric acid and 2 to 3 mL of methyl orange acidic indicator. Then saturate the solution with a salt, usually sodium sulfite or sodium chloride, at the temperature at which the Orsat is expected to operate. (The sulfuric acid acts as a drying agent to remove any moisture from the sample, and the saturated salt solution prevents the absorption of sample gases by the leveling solution.) This leveling bottle solution should be prepared as a stock solution and stored in case it is needed.

2. Remove and clean the stopcocks. Carefully apply stopcock grease to prevent system leaks and do it without plugging the air passages. Stopcocks are generally not interchangeable, so replace each one in the same port from which it was originally taken.

3. Change the absorbing solutions if more than 10 passes are needed to obtain a constant reading for any gas component. If in doubt, change the solution (following the manufacturer's instructions) by emptying the absorber and adding fresh absorbing reagents. Add new reagents when required, 6 to 8 h prior to field use. Prior to adding the O_2 reagent, flush the absorbing pipette and the expansion bag with N_2, and pass N_2 over the reagent while adding it to the pipette.

4. Leak check the Orsat analyzer thoroughly before using it. Use the procedure in Section 1.5.1.9. If there are leaks, check all connections and stopcocks until the cause of the leak is identified. Leaking stopcocks must be disassembled, cleaned, and regreased. Leaking rubber connections must be replaced. After the analyzer is reassembled, the leak-check procedure must be repeated.

3.3 CEMS Pretest Procedures

The quality assurance activities for presampling operations are summarized in an activity matrix, Table 3.1, at the end of this section. A pretest preparation checklist, Figure 3.11, is provided.

3.3.1 Checking the Apparatus -

3.3.1.1 Sampling Train - An example CEMS sampling train is depicted in Figure 3.10. Commercial models are available, or sampling trains can be manufactured in-house if the apparatus complies with specifications.

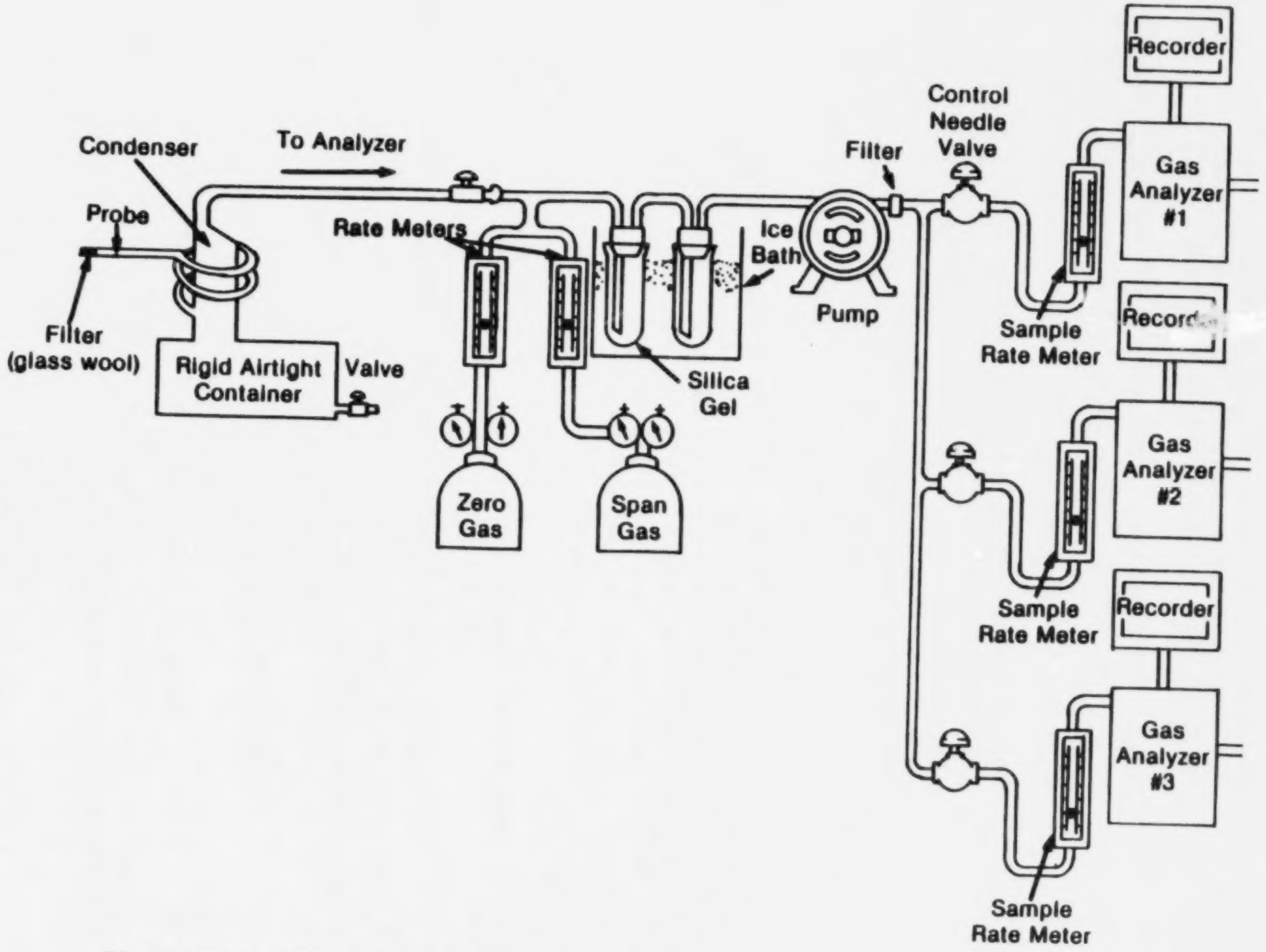

Condenser
To Analyzer
Probe
Filter (glass wool)
Rigid Airtight Container
Valve
Rate Meters
Zero Gas
Span Gas
Silica Gel
Ice Bath
Pump
Filter
Control Needle Valve
Sample Rate Meter
Gas Analyzer #1
Recorder
Sample Rate Meter
Gas Analyzer #2
Recorder
Sample Rate Meter
Gas Analyzer #3
Recorder

Figure 3.10. Typical Continuous Emission Monitoring System (CEMS) Sampling Apparatus

3.3.1.2 Probe - The probe should be cleaned internally by brushing first with tap water, then with deionized and distilled water, and finally with acetone. Allow the probe to air dry; the objective is to leave the probe contaminant free. Then place the glass wool in the end of the probe. The probe should be sealed and then leak checked at a vacuum of 380 mm (15 in.) Hg. See Section 3.3.2 for leak-check procedures.

3.3.1.3 Condenser - The condenser should be cleaned with tap water, then with deionized distilled water, and finally rinsed with acetone and allowed to air dry. The objective is to leave the condenser contaminant free. Leak check the condenser as described in Section 3.3.2.

3.3.1.4 Needle Valve and Rotameter - The metering valve and rotameter should be cleaned according to the manufacturer's recommendations prior to each use or on any sign of erratic behavior. After the rotameter is cleaned, it should be recalibrated (Section 2.10).

3.3.1.5 Vacuum Pump - The vacuum pump should be inspected for damage and leaks before each use. Leak test the pump as described in Section 3.3.2.

3.3.2 Installation and Calibration - Install the apparatus as illustrated in Figure 3.10. The placement of auxiliary filters, dryers, or gas conditioning devices (e.g., Ascarite to remove CO_2) is dictated by the requirements of the particular analyzers used. First, place a loosely packed filter of glass or steel wool in the end of the probe (if a probe filter is used) and install the probe. Fill the condenser with ice or coolant. Place new filters in auxiliary filter holders and fill drying tubes or other gas conditioning devices with the appropriate materials (e.g., silica gel or ascarite). During assembly of the sampling train, keep all openings covered to prevent contamination.

After the equipment is assembled:

1. Leak check the train just before sampling by placing a gauge at the probe inlet and pulling a vacuum of $\geq$250 mm (10 in.) Hg. Turn the pump off. Note: The vacuum should remain stable for at least 30 s. If not, find and eliminate that leak before slowly releasing the vacuum gauge. This leak check is optional.

2. Connect the gas analyzer to electrical service and allow it to warm up according to the manufacturer's recommendations (minimum of 2 h). Whenever possible, a overnight warm-up is preferred.

3. Perform a multipoint calibration (Section 2.11.2.1).

4. Connect the analyzer to the sampling train, as illustrated in Figure 3.10, and insert the probe into the stack at the predetermined sampling point.

5. Plug the sampling port to prevent dilution of the stack gas by in-leakage of ambient air.

6. Immediately adjust the gas flow rate to that recommended by the analyzer manufacturer; the flow rate must be $\leq$1 L/min (0.035 ft^3/min). Purge the system by drawing at least five times the sampling system volume through the train or by drawing until the analyzer reading stabilizes.

7. Check the strip chart recorder (if used) for proper operation:
   a. chart speed control setting,
   b. gain control setting,
   c. ink trace readability,
   d. excess noise, and
   e. proper zero setting.

3.4 Summary of Pretest Procedures

Figure 3.11 contains a checklist to assist in performing each of the Method 28A procedures. Table 3.1 contains an activity matrix for each of the activities discussed in this section. The purpose, acceptance limits, time, and frequency of each activity are provided.

Activity	Acceptable	
	Yes	No
I. PROCESS OPERATION CHECKS		
Measurement of Firebox Volume		
1. Firebox dimensions measured from actual wood heater to be tested?	____	____
2. Firebox dimensions checked against engineering drawings?	____	____
3. Firebox volume calculated?	____	____
4. Volume determination documented including calculations, illustrations, and volume adjustments?	____	____
5. Volume determination independently calculated and confirmed?	____	____
Wood Heater Installation		
6. Flue pipe cleaned and assembled leak-free?	____	____
7. Flue pipe and solid pack chimney installed to allow unobstructive vertical scale movement?	____	____
8. Liquid seal level checked (if applicable)?	____	____
General Comments		

Figure 3.11. Checklist for Method 28A Pretest Procedures

Activity	Acceptable	
	Yes	No
Wood Heater Installation (Continued)		
9. Induced draft measured and adjusted to less than 0.005 in. H_2O?	____	____
10. Flue pipe sampling ports in location above 7.5 ±0.5 ft above platform scale?	____	____
Apparatus Check and Calibrations		
11. Calibration records checked and verified for platform scale?	____	____
12. Calibration records checked and verified for optional fuel balance?	____	____
13. Platform scale single-point calibration checked and acceptable?	____	____
14. Moisture meter calibration performed and recorded?	____	____
15. Calibration records checked and verified for anemometer?	____	____
16. Calibration records checked and verified for barometer?	____	____
17. Calibration records checked and verified for relative humidity gauge?	____	____
General Comments		

Figure 3.11. Checklist for Method 28A Pretest Procedures (Continued)

Activity	Acceptable	
	Yes	No
Apparatus Check and Calibrations (Continued)		
18. Calibration records checked and verified for draft gauge?	____	____
19. Calibration records checked and verified for temperature monitors?	____	____
Test Fuel Measurements		
20. Moisture content of each test fuel piece measured?	____	____
21. Moisture readings, fuel temperature, and meter correction factors documented?	____	____
22. Test fuel pieces conform to the grade and dimensional specifications required?	____	____
Test Fuel Crib Construction		
23. Test fuel length approximately 5/6 the length of the firebox?	____	____
24. Length of each test fuel piece documented?	____	____
25. Test fuel crib configuration documented?	____	____
26. Test fuel crib meets weight and nominal size specifications?	____	____
General Comments		

Figure 3.11. Checklist for Method 28A Pretest Procedures (Continued)

Activity	Acceptable	
	Yes	No
II. ORSAT INTEGRATED SAMPLING CHECKS		
1. Probe inserted at centroid of flue pipe and sealed?	____	____
2. Filters (in probe or external) replaced?	____	____
3. Vacuum pump leak checked and operating properly?	____	____
4. Condenser cleaned and filled with ice or coolant (if necessary), moisture drain closed?	____	____
5. Flexible bags leak checked?	____	____
6. Rotameters operating properly and calibration records checked?	____	____
7. Orsat analyzer reagent condition checked?	____	____
8. System leak checked?	____	____

General Comments

Figure 3.11. Checklist for Method 28A Pretest Procedures (Continued)

Activity	Acceptable	
	Yes	No
III. CEMS PRETEST CHECKS		
1. Probe inserted at centroid of flue pipe and sealed?	____	____
2. Filters (in probe or external) replaced?	____	____
3. Vacuum pump leak checked and operating properly?	____	____
4. Condenser cleaned and filled with ice or coolant, moisture drain closed?	____	____
5. Rotameters cleaned and calibrated?	____	____
6. Analyzers warmed up >1 h?	____	____
7. Multipoint calibration performed?	____	____
8. System leak checked?	____	____
9. Sample flow set at same rate used during calibration?	____	____
10. Sample system purged?	____	____

General Comments

Figure 3.11. Checklist for Method 28A Pretest Procedures (Continued)

TABLE 3.1. ACTIVITY MATRIX FOR PRETEST PROCEDURES

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Process Operation Checks			
Measurement of usable firebox volume	See Section 3.0 of this manual	Once by the testing team and once by the auditor; and compared prior to the test	
Wood heater installation	Heaters must be installed as per Section 3.0 of this manual	Once prior to test	
Apparatus check and calibration	Apparatus must meet calibration specifications described in Section 2.0 of this manual	Review all equipment records prior to each test; moisture meter should be calibrated before each use; a single-point calibration check should be performed on the platform scale prior to each certification run	
Test fuel moisture measurements	Between 16 and 20% moisture content on a wet basis (19-25% dry basis)	Within 4 h of the start of each test; the moisture content of pretest fuel must also be measured	
Test fuel crib construction	Test fuel charge specifications as per Section 3.1.6	One test fuel crib must be constructed before each certification test	

TABLE 3.1. ACTIVITY MATRIX FOR PRETEST PROCEDURES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Pretest facility measurements	Temperature $\leq 90^{\circ}$F, air velocity ≤ 50 ft/min	Before each applicability certification determination test run	
Pretest burn	At least 1 h at burn rate category 1 or minimum burn rate	Immediately before each test; pretest burn must begin a minimum of 1 h prior to starting the test	
Orsat Integrated Gas Sampling Train Checks			
Probe	No visual sign of breakage	Visual observation before each field test	Replace as necessary
Air-cooled condenser	No visual sign of breakage	Visual observation before each field test	Clean and replace as necessary
Needle valve and rotameter	No foreign matter or erratic behavior	Visual observation before each field test	Clean and reassemble as necessary
Flexible bags	No visual indication of leakage	Visual observation before each field test	Replace as necessary
Pump	According to manufacturer's criteria	Before each field test, use manufacturer's directions	Service or return to supplier as necessary

TABLE 3.1. ACTIVITY MATRIX FOR PRETEST PROCEDURES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Gas Analyzer			
Leveling solution	Distilled water containing approximately 5% by volume of concentrated H_2SO_4 and saturated with a salt		Prepare fresh solution
Absorbing solution	<10 passes needed for constant readings with any component gas	Performance check using any component gas	Use fresh reagent
Stopcocks	No leakage	Visual observation	Remove, clean, regrease as necessary
CEMS Apparatus Check and Calibration			
Probe	Free of contaminants; leak free	Clean internally by brushing, using tap water, deionized distilled water, and acetone, air dry; seal and check for leaks at 380 mm (15 in.) Hg prior to use	Repeat cleaning procedure; repair or replace
Condenser	Free of contaminants; leak free	Clean internally by brushing, using tap water, deionized distilled water, and acetone, air dry; seal and check for leaks at 380 mm (15 in.) Hg prior to field use	Repeat cleaning procedure; repair or replace

TABLE 3.1. ACTIVITY MATRIX FOR PRETEST PROCEDURES (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Needle valve and rotameter	Clean and without signs of erratic behavior	Clean by manufacturer's recommendations prior to use or at sign of erratic behavior	Repair or return to manufacturer
Vacuum pump	No damage or leaks; full oiler jar (if required)	Before use; visually inspect for damage; check oil level; leak check as described in Section 2.0	Repair or replace
Assembling sampling train	Meets specifications in Figure 3.10 or as required	Before each sampling	Reassemble
Instrumental analyzers and sampling system	Leak checked, no deflection on a vacuum gauge for a 30-s determination, leak check after sampling (same as above); low-level and high-level readings within 2% of predicted values	Leak check the system; multipoint calibration before each test; adjust zero and mid-level settings within 1 h of starting test	Correct the leak; recalibrate or repair analyzer

4.0 TEST RUN PROCEDURES

The procedures for conducting a test run may be categorized as follows:

1. Starting the test run,
2. Data recording,
3. Adjustments during the test run, and
4. Completion of the test run.

The activity matrix, presented at the end of this section in Table 4.1, shows the sequence of events and the time during which each activity should be performed. Operation of the wood heater--maintaining primary and secondary air settings and operating the auxiliary equipment--is an integral part of test run procedures. The testing team should be familiar with the operation of the wood heater being tested and the activity matrix so that each activity is performed in a timely fashion and in accordance with Method 28.

4.1 Starting the Test Run

This section describes the activities that are performed and the requirements that must be met before the test fuel is loaded and before emissions sampling begins.

4.1.1 Requirements for Starting the Test Run - Two pretest fuel requirements must be satisfied before the test run is started. First, the pretest fuel must have been consumed to leave a coal bed weight between 20 and 25% of the weight of the test fuel charge. For example, if a 10-kg test fuel charge is required, then the test run begins when the remaining pretest fuel weighs between 2.0 and 2.5 kg. This coal bed weight must not include dead ash added before the test run begins. Any dead ash must be included in the wood heater tare weight and any added ash must be dry before weighing.

The second requirement is that uniform charcoalization of the pretest fuel must be achieved. That is, the pretest fuel bed should not contain large pieces of wood. This condition is achieved by breaking up the larger pieces of fuel or by removing the large pieces from the coal bed altogether. Large pieces of wood may be removed from the coal bed up to 15 min before the start of the test run. Adding fresh fuel prior to the start of the test run is not recommended unless addition of fresh fuel is necessary to satisfy the first requirement (i.e., if the remaining pretest fuel weighs less than 20% of the test fuel load). Fresh fuel will require additional time to achieve a uniform coal bed.

Wood heater or pretest fuel adjustments, other than coal raking, are not permitted within 15 min of starting the test run. Therefore, all air settings must have been adjusted to the lowest or most closed position before 15 min prior to starting the test. If adjustments have been made within the past 15 min, then the start of the test run must be delayed until a 15-min interval without adjustment has passed. The test run may start when the conditions above have been met.

4.1.2 Final Pretest Measurements - As soon as the requirements for starting the test run have been satisfied, record the final test facility measurements (shown in Figure 3.8). The initial weight of the test fuel charge should be recorded on a form such as Figure 4.1.

4.1.3 Gas Sampling - Gas sampling begins after the final pretest measurements have been made and before the test fuel crib is loaded. The sampling procedures described in Sections 3.2 or 3.3 should be followed.

For Orsat integrated sampling, the vacuum pump should be running with the rotameters set at the predetermined sample rate. Connect the two flexible bags immediately upon starting the test. Record the rotameter readings on a form such as Figure 4.1 at time equals 0 min.

For CEMS, verify that the flow rate and pressure gauge readings are the same as during calibration. Record the gas concentration readings for O_2, CO_2, and CO on a form such as Figure 4.1 at time equals 0 min.

DO NOT QUOTE OR CITE

DATE OF TEST: 3-30-88	WOOD HEATER MANUFACTURER: Fake fire Inc	TEST FACILITY: ABC Testers	
OPERATOR: J.S.	WOOD HEATER MODEL: Firebox 2000	SHEET NUMBER: 2 of 2	

Time (min)	Test Fuel Scale Reading Remaining (lb)	Change in Test Fuel Weight (lb)	Concentration			Flow Rate				Room Temp. (°F)	Flue Draft (in. H_2O)	Adjustments/Remarks
			O_2	CO_2	CO	#1	#2	#3	#4			
80	1.2	.2	15.4	4.9	.050	1.5	1.5	1.4		78	.065	
90	1.1	.1	15.2	4.9	.056	1.4	1.5	1.5		78	.064	
100	1.0	.1	15.4	4.7	.065	1.5	1.5	1.5		77	.063	
110	0.9	.1	15.5	4.8	.074	1.5	1.5	1.5		76	.063	
120	0.8	.1	15.5	4.8	.082	1.5	1.5	1.5		76	.060	
130	0.7	.1	15.6	4.6	.085	1.4	1.5	1.5		74	.059	
140	0.6	.1	15.8	4.5	.089	1.5	1.5	1.5		75	.058	
150	0.5	.1	16.1	4.3	.091	1.5	1.6	1.5		74	.055	
160	0.4	.1	16.2	4.1	.092	1.5	1.5	1.5		76	.050	
170	0.3	.1	16.8	3.9	.090	1.5	1.5	1.5		74	.050	
180	0.2	.1	17.0	3.8	.091	1.5	1.5	1.5		73	.050	
190	0.1	.1	17.1	3.2	.091	1.5	1.5	1.5		73	.050	
200	0.0	.1	17.1	3.0	.087	1.5	1.5	1.5		72	.050	End at
												10:05 pm

Figure 4.1. Test Measurements Recording Sheet

4.1.4 Test Fuel Loading - The test fuel should be loaded within 1 min of starting gas sampling. Several factors should be considered when placing the test fuel in the firebox. The planned crib arrangements should be maintained. The test fuel spacers should be parallel to the floor of the firebox, and the spacer edges should be adjacent to each other (see Figure 3.7). To avoid any unexpected loading difficulties, the crib arrangement should be tested prior to ignition to see if it will fit in the firebox. If loading difficulties result, some fuel pieces may be placed on edge. Any adjustments in the construction of the crib arrangement should be determined before the test. For example, it may be necessary to remove spacers from the test fuel pieces in the top row so that the test fuel crib can fit into the firebox.

4.2 Data Recording

Pretest and test run measurements should be recorded on a form similar to Figure 4.1 (wood heater and test fuel adjustments can be recorded as well). This form must be maintained as part of the applicability determination documentation. During the test, record the following data every 10 min (or more often if desired):

- elapsed time,
- remaining fuel weight,
- change in fuel weight (since last reading),
- facility temperature,
- concentration of CO_2, O_2, and CO (for CEMS),
- flow rate (for each Orsat bag, or for each gas analyzer), and
- flue draft gauge reading.

Flow rate measurements are not required for instrumental analyzers if the instruments are documented to be not sensitive to flow rate changes.

For CEMS, gas concentration readings for O_2, CO_2, and CO can be documented by strip chart readings. Strip charts should be maintained as part of the test record with the corresponding calibration curve (see Figure 2.9).

4.3 Adjustments During the Test Run

Once the test run has started, the wood heater door may remain open up to 5 min. After this, only limited wood heater and test fuel adjustments are permitted. A discussion of the types of adjustments permitted by Method 28A follows.

4.3.1 Wood Heater Adjustments

- Adjustments may not be made to any secondary air supply setting, if provided. Secondary air settings must be in the full closed position. Other auxiliary equipment may be adjusted only once apiece during the test run. A common example of auxiliary equipment that may require adjustments is a shaker grate. Adjustments to the primary air supply setting are not permitted. Blowers should be set in the high position during the test. The testing team should be familiar with the manufacturer's operating instructions in order to identify any recommended adjustments before the test starts. Any adjustments should be recorded on a form such as Figure 4.1.

4.3.2 Test Fuel Adjustment

- It may be necessary to adjust the test fuel load during the test run to prevent the fire from going out. A test fuel adjustment may be made only if the following two conditions apply: (1) more than 60% of the initial test fuel charge weight has been consumed and (2) more than 10 min have elapsed without a measurable (<0.05 kg [0.1 lb]) weight change or a change of less than 1% of remaining fuel weight. Only one such test fuel adjustment is permitted, and the time used to make this adjustment must be less than 15 s. If the fire is in danger of going out more than one time, the wood heater is probably not designed to operate at a low burn rate, and the test run should be conducted at another burn rate. The test fuel adjustment should be recorded on a form such as Figure 4.1.

4.3.3 Sample Flow Adjustments - Sample flow requirements depend on the system used. For Orsat integrated gas sampling, a constant sampling rate is required. The flow rate is determined prior to starting the test. During the test, adjust the needle valve, if necessary, so that a constant flow rate is maintained. The flow rate into each flexible bag should not vary more than 10%.

For CEMS, the flow rate and pressure should be maintained at the same values used during calibration. Adjust the needle valve as necessary, if required.

4.3.4 Sample System Adjustments - During the test, observe the condition of the filters, the gas conditioner reagents (e.g., silica gel), and the condenser water level. If filter clogging is evidenced by an increase in sample system vacuum, filters may be replaced if sampling is interrupted during replacement. Perform this operation as quickly as possible and record on a form such as Figure 4.1. Likewise, the condenser drain valve can be opened, or drying agent replaced, if condensation develops or if the drying agent appears saturated. These operations should not be required if new filters and reagents are used.

4.4 Completion of the Test Run

The test run is completed when the weight of the test fuel charge is 0.0 kg (i.e., when the platform scale reading reaches the tare weight that was set just before the test fuel was added). At the completion of the test, record all final measurements and stop gas sampling. If the Orsat analyzer method is used, disconnect, seal, and remove the two flexible sampling bags to the analysis area. If the testing team desires to conduct consecutive tests on the same wood heater, a minimum of 1 h must elapse before another test can begin.

TABLE 4.1. ACTIVITY MATRIX FOR TEST RUN PROCEDURES

Activity	Time of Activity
1. Start the Test Run	When the weight of the remaining pretest fuel is between 20 and 25% of the test fuel weight (and no adjustments other than coal bed raking have been made in the last 15 min).
2. Record Final Pretest Fuel Weight	Immediately following the start of the test.
3. Begin Emissions Sampling	Immediately following the start of the test.
4. Load Test Fuel	Within 1 min of starting the test run.
5. Record Test Run Measurements a. Remaining test fuel weight b. Draft gauge readings c. Facility temperature d. Sampling train and flow rate measurements	At 10-min intervals following the start of the test run.
6. Make Wood Heater Adjustments (if necessary)	Once during the test run.
7. Make Test Fuel Adjustments (if necessary)	Once after 60% of the initial test fuel weight has been consumed and more than 10 min have elapsed without a measurable weight change.
8. Make Sample Flow Rate Adjustments (if necessary)	If flow rates vary from specifications: >10% for Orsat method, outside calibration range for CEMS.
9. Make Sample Train Adjustments (if necessary)	If filters clog, or condensers or dryers saturate.
10. Complete Test Run, End Sampling	When the remaining test fuel weight reaches 0.0 kg.

5.0 POST-TEST PROCEDURES

This section describes the procedures that are followed after the sampling ends. These procedures are grouped into four categories: (1) facility and process measurements, (2) sample system leak check and equipment calibration check, (3) sample analysis and determination of gas concentrations for the Orsat analyzer method, and (4) data validation (quality assurance) procedures. Table 5.1, at the end of this section, summarizes the post-test procedures.

5.1 Facility and Process Measurements

5.1.1 Test Facility Condition Measurements - Immediately following each test run, the air velocity, relative humidity, barometric pressure, and air temperature in the test facility must be measured as described in Section 3.1.7. (It is not necessary to measure induced draft at this time.) These measurements should be recorded on a form such as Figure 3.8. The test facility condition measurements must be included in the applicability determination test record.

5.1.2 Post-Test Acceptance Checks - If a liquid seal is used, the oil level should be checked following each test run. If the level has dropped to a point that corresponds to an oil weight loss of more than 0.05 kg (0.1 lb), then the data quality will be adversely affected. The liquid seal should be repaired before the start of the next test if a leak is indicated.

5.2 Equipment Leak Checks and Calibrations

5.2.1 Orsat Analyzer Method - Leak check the sample system according to the procedure described in Section 3.2. If a leak is detected on the suction side (i.e., between the probe and the vacuum pump), then the test is invalid. A leak would result in a measured air-to-fuel ratio that is higher than actual.

Calibration of each rotameter used during sampling should be verified by a post-test check which is similar to the initial calibration (Section 2.10) with the following variations:

1. The metering system should not have had any leaks corrected prior to the post-test check.
2. Only two flow rate checks need to be made. If the rotameter calibration factor (Y_r) does not deviate >10 percent from the initial calibration factor, the rotameter operation is acceptable. If it does, the rotameter should be cleaned and recalibrated, but no calculations need be corrected.

5.2.2 CEMS - Remove the probe from the flue pipe, place a vacuum gauge at the inlet and perform a leak check as in Section 3.3.2. If a leak is detected on the suction side of the vacuum pump, then the test is invalid and should be repeated.

Check the zero and mid-span drift for each gas analyzer. Do not turn off the analyzers after the test before the calibration check. Use the procedures described in Section 2.0, but make no adjustments to the equipment. Record the unadjusted results on a form such as Figure 2.10. If the results differ from the calibration gas values by more than 0.2 percent by volume, then the test should be repeated. Alternatively, the analyzer readings can be corrected and the results calculated using both corrected and uncorrected data sets. The corrected results may be acceptable at the option of the Administrator.

5.3 Data Retrieval

This section describes the procedures to interpret the data and/or samples taken during the test.

5.3.1 Orsat Method - This subsection describes the procedures used to analyze the samples taken.

5.3.1.1 Setup and Leak Check - After the test sampling ends, allow the collected sample to sit for about 30 min to ensure thorough mixing and temperature equilibrium. It is recommended that the analysis be performed as soon as practical after the 30-min waiting period, but not more than 4 h after sampling.

Set up the Orsat apparatus as shown in Figure 1.9. It is recommended that fresh reagents be used. Leak check the Orsat analyzer as described in Section 1.5.1.9. The leak check must also be performed after analysis. If the leak check is satisfactory, purge the Orsat by drawing in sample gas and then expelling it. Repeat this procedure 10 times.

5.3.1.2 Orsat Analysis Procedure - Perform the Orsat analysis for each of the bag samples immediately after the leak check according to the manufacturer's instructions and as follows:

1. Draw sample gas into the Orsat analyzer and flush (i.e., allow to bubble through the burette) at least three times to saturate the liquid in the burette with the gas being analyzed and to ensure that the air remaining in the manifold is of the same composition as the sample to be analyzed. Caution: Once the flushing has begun, ambient air must not be allowed to enter the manifold.

2. Draw in a fixed volume (usually 100 mL) of the sample gas, following the manufacturer's instructions. Allow a minimum of 5 min for the sample gas to come to temperature equilibrium with the water jacket around the burette (unless the sample and the analyzer have both been at the same temperature for at least 5 min).

3. Proceed with the sequential determinations of CO_2, O_2, and CO as directed by the instructions supplied by the manufacturer of the gas analyzer. Make repeated analyses of each component until two consecutive readings differ by <0.2% concentration. Always make two or three passes through the absorbing solution between readings. Note: If more than three readings of two or three passes are required to reach a constant reading for any component gas, replace the absorbing reagent and repeat the entire sampling sequence.

4. Record the readings on a data sheet such as Figure 5.1 and determine the average value for each component of interest.

Test Facility Manufacturer ABC Testers / Fakefire Inc
Wood Heater Model
Date 3/30/88
Test Number #1

Sampling Time 6:00-10:05 PM
Sample Bag Number #1
Ambient Temperature 78 oF
Operator J.S

Run Gas	1		2		3		
	Actual Reading	Net	Actual Reading	Net	Actual Reading	Net	Average Net Volume
CO_2	4.5%	4.5%	4.8	4.8	4.6	4.6	4.63
O_2 (Net is Actual O_2 Reading Minus Actual CO_2 Reading)	22.3	17.8	22.7	17.9	22.5	17.9	17.87
CO (Net is Actual CO Reading Minus Actual O_2 Reading)	23.1	0.8	23.8	1.1	23.4	0.9	0.93

Figure 5.1. Orsat Analyzer Gas Analysis Sheet

5. Leak check the Orsat after analysis. If it does not pass the leak test, repair it and repeat the analysis.

5.3.1.3 Special Precautions - The Orsat analyzer is a simple instrument, but the validity of results depends on operator technique, care, and patience. Special precautions for using an Orsat analyzer include the following:

1. Do not allow ambient air to enter the Orsat analyzer during testing.
2. Always perform the analysis in the following sequence: absorber No. 1 - CO_2, absorber No. 2 - O_2, and absorber No. 3 - CO. This sequence is necessary because absorber No. 2 will also absorb CO_2, and absorber No. 3 will absorb O_2 and possibly CO_2; double absorption will yield erroneous data.
3. Be sure to saturate the indicating solution in the burette with salt at the operating temperature to prevent absorption of sample gases prior to analysis. Be sure the solution is acidic (as indicated by methyl orange) to enable it to absorb any moisture in the sample gas.
4. Keep the absorber solution from entering the capillary column manifold. Void the test if any absorber solution enters the manifold and clean the sample manifold with acetone.
5. Allow a minimum of 5 min for gas samples to come to temperature equilibrium with the water jacket before the analysis.
6. Operate the Orsat analyzer under constant temperature and pressure. Be sure that the levels of solutions in the burette and the leveling bottle are the same to ensure equal pressures before taking a reading from the Orsat. The water jacket acts as a buffer for temperature changes.

5.3.2 CEMS - Data from instrumental analyzers may be used directly if the instrument readout is calibrated accordingly. Otherwise, convert the data (e.g., strip chart readings) by using the calibration curve developed before the test (see Figure 2.9).

5.4 Data Validation Procedures

5.4.1 Orsat Analyzer Method - Determine the gas concentrations (percent O_2, percent CO_2, and percent CO) for each of the bag samples independently. Remember to purge the Orsat analyzer after connecting each bag. Compare the concentrations for two (or more) bag samples. For each gas concentration, the difference from one bag to another should not exceed 0.5% by volume.

If the values for each gas concentration for each sample bag are within 0.5 percentage points, average the concentrations for each gas and use the resultant averages to calculate the results (see Section 6.3). If the values for each gas concentration are not within 0.5 percentage points, calculate the results independently for each bag sample. Do not average the concentration results from different bags for any of the gas concentrations (see Section 6.2.1).

Calculate an F_o factor by using the final average gas concentrations with Equation 6.5 (see Section 6.4). If the value is not in the range 1.00 to 1.12, the analysis should be repeated. If the second analysis results in an F_o factor in the correct range, use those results. If not, repeat the sampling procedure.

5.4.2 CEMS - Calculate the fuel factor, F_o, for each 10-min sampling period (see Section 6.4). If the F_o factor is not in the correct range for any 10-min period, examine the data for a correctable error. If an error is not detected, repeat the test or correct the concentration results (see Section 6.4). Both corrected and uncorrected data must be recorded in the test record.

TABLE 5.1. ACTIVITY MATRIX FOR POST-SAMPLING OPERATIONS

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Record air velocity, relative humidity, barometric pressure, facility temperature	Air velocity $\leq$50 ft/min, temperature $\leq$90°F	At end of test	Repeat test
Check liquid seal oil level	Weight loss <0.1 lb	At end of test	Repair liquid seal
Orsat Integrated Sampling			
Sample train	No leaks; vacuum stable for $\geq$30 s	Pull vacuum of at least 250 mm (10 in.) Hg	Check all connections, replace items as necessary
Sampling rate check	Constant rate within 10%	Check 10-min readings	Repeat sampling to meet 10% deviation limit
Orsat analyzer leak check	No leaks for 4 min	Mandatory (see Section 1.5)	Check rubber connections and stopcocks until cause of leak is identified; leak check after repair and reassembly

TABLE 5.1. ACTIVITY MATRIX FOR POST-SAMPLING OPERATIONS (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
CEMS			
Instrumental analyzers	Within 0.2% concentration of pretest calibration	After testing, check zero and mid-level values per Section 2.11	Recalibrate and void all data back to last acceptable check
Rotameter	Within ±10% of desired flow rate	Make two independent checks (Section 2.10)	Clean and recalibrate

6.0 CALCULATIONS

The procedures for calculating the dry burn rate, the sample gas concentrations, and the air-to-fuel (A/F) ratio, as well as for performing fuel factor, F_0, calculations associated with data validation, are presented in this section. Calculation sheets and example calculations are also provided, where applicable. When performing calculations, at least one extra decimal figure beyond that of the measured data should be retained. After the final calculations have been made, the extra figures can be rounded off.

Calculation errors due to mathematical mistakes can be a large part of total system error. Therefore, each set of calculations should be repeated or spot-checked by a team member other than the one who performed them originally. If a difference greater than a typical round-off error is detected, the calculations should be checked step by step until the source of error is found and corrected.

A computer program can be advantageous in reducing calculation errors. If a standardized computer program is used, check the original data entries. If differences are observed, make a new computer run.

6.1 Dry Burn Rate

Calculation of the dry burn rate is required once for each test. The dry burn rate is a function of (1) the total mass of test fuel burned, (2) the average moisture content of the test fuel charge, and (3) the test run duration. The equation for calculating the dry burn rate is:

$$BR = \frac{60\ W_{wd}}{\theta} \times \frac{(100 - \%M_w)}{100} \qquad \text{Equation 6.1}$$

where: BR = Dry wood burn rate, kg/h (lb/h);

W_{wd} = Total mass of wood burned during the test run, kg (lb);

θ = Total time of test run, minutes;

$\%M_W$ = Average moisture in test fuel charge, wet basis, percent;

$\%M_D$ = Average moisture in test fuel charge, dry basis, percent.

Note:

$$\%M_W = \frac{100 \times \%M_D}{100 + \%M_D}$$

The total mass of wood burned during the test run and the test run duration can be taken directly from the Test Run Measurements Recording Sheet (Figure 4.1). The average moisture content can be taken from the Test Fuel Measurements Sheet (Figure 3.5). When performing the dry burn rate calculation, at least one decimal figure should be retained beyond the resolution of the measurement equipment.

6.2 Sample Gas Concentrations

6.2.1 Orsat Analyzer -

$\%O_2$ = Average of at least two O_2 percent bag analyses that do not differ by more than 0.5 $\%O_2$.

$\%CO_2$ = Average of at least two CO_2 percent bag analyses that do not differ by more than 0.5 $\%CO_2$.

%CO = Average of at least two CO percent bag analyses that do not differ by more than 0.5 %CO.

Note: Each bag analysis is the average of three to four absorption passes for which the resultant individual gas concentrations do not differ more than 0.2% concentration. If the bag averages differ more than 0.5% concentration, calculate the air-to-fuel (A/F) results using both data sets (i.e., A/F_1 = bag one and A/F_2 = bag two).

6.2.2 CEMS -

$\%O_2$ = Average of all O_2 percent values obtained during the test.

$\%CO_2$ = Average of all CO_2 percent values obtained during the test.

$\%CO$ = Average of all CO percent values obtained during the test.

Note: If data were recorded at irregular time intervals, a time-weighted average must be used. For example, if some concentrations were only for 5 min but the remainder were for 10 min, the 5-min readings and the number of such readings should be multiplied by 5 min/10 min = 0.5 before averaging.

6.3 Air to Fuel Ratio

Method 28A calculates the air to fuel ratio as a function of the molecular weight of the stack gas, M_d, and the dry moles of exhaust gas, N_T. The following nomenclature is used:

M_d = Dry molecular weight, g/g-mol (lb/lb-mol).

$\%CO_2$ = Percent CO_2 by volume (dry basis).

$\%O_2$ = Percent O_2 by volume (dry basis).

$\%CO$ = Percent CO by volume (dry basis).

$\%N_2$ = Percent N_2 by volume (dry basis).

N_T = Total gram-moles of dry exhaust gas per kilogram of wood burned (lb-mol/lb).

Y_{CO_2} = Measured mole fraction of CO_2 (e.g., 10% CO_2 = 0.10 mol fraction), g/g-mol (lb/lb-mol).

Y_{CO} = Measured mole fraction of CO (e.g., 1% CO = 0.01 mol fraction), g/g-mol (lb/lb-mol).

Y_{HC} = Assumed mole fraction of HC (dry as CH_4);
= 0.0088 for catalytic wood heaters;
= 0.0132 for noncatalytic wood heaters; and
= 0.0080 for pellet-fired wood heaters.

0.280 = Molecular weight of N_2 or CO, divided by 100.

0.320 = Molecular weight of O_2, divided by 100.

0.440 = Molecular weight of CO_2, divided by 100.

42.5 = Gram-moles of carbon in 1 kg of dry wood, assuming 51% carbon by weight dry basis (0.0425 lb-moles/lb).

510 = Grams of carbon in exhaust gas per kilogram of wood burned.

1000 = Grams in 1 kg.

First, the dry molecular weight of the stack gas is determined.

$$M_d = 0.440 \times \%CO_2 + 0.320 \times \%O_2 + 0.280 \times (\%N_2 + \%CO) \qquad \text{Equation 6.2}$$

where: $\%N_2 = 100 - (\%CO_2 + \%O_2 + \%CO)$

Note: The above equation does not consider argon in air (about 0.9%, molecular weight of 37.7). Therefore, the actual molecular weight of the stack gas is about 0.4% higher. The tester may include argon in the calculation of M_d by using procedures subject to the approval of the administrator.

Next, N_T, the dry moles of exhaust gas, is calculated.

$$N_T = \frac{42.5}{(Y_{CO_2} + Y_{CO} + Y_{HC})} \qquad \text{Equation 6.3}$$

Finally, the air-to-fuel ratio is calculated.

$$A/F = \frac{(N_T \times M_d) - 510}{1000} \qquad \text{Equation 6.4}$$

6.4 CEMS Data Verification Calculations

A fuel factor, F_o, is calculated for each 10-min period. The fuel factor should be in the range 1.000 to 1.120 for wood fuel. Calculated values beyond this range should be investigated before accepting test results. F_o is calculated as

$$F_o = \frac{20.9 - (\%O_2 - 0.5\ \%CO)}{\%CO_2 + \%CO} \qquad \text{Equation 6.5}$$

If F_o is not in the correct range for each 10-min period, examine the data for a correctable error. If none is detected, repeat the test. Alternatively, correct the values for CO_2 and O_2 for each such 10-min period, assuming an F_o value of 1.05 and a CO value of 0. Then recalculate the results. For example, for a 10-min period,

$\%O_2 = 16.1$

$\%CO_2 = 3.7$

$\%CO = 0.32$

Therefore,

$F_o = 1.23$

If $F_o = 1.05$ and $\%CO = 0$, then assume $\%O_2$ is correct:

$$1.05 = \frac{20.9 - 16.1}{\%CO_2}$$

and thus $\%CO_2 = 4.57$

Change the $\%CO_2$ data for that 10-min period from 3.7% to 4.57% and recalculate the results.

7.0 MAINTENANCE

The normal use of testing equipment subjects it to extremes in temperature or other conditions that may affect the reliability of the equipment. Keeping the equipment in good operating order over an extended period of time requires knowledge of the equipment and a routine maintenance program which should be performed at least quarterly. Maintenance procedures for the various instruments are summarized in Table 7.1 at the end of this section.

7.1 Platform Scale

The platform scale should be maintained according to the manufacturer's instructions. Generally, the scale should be protected from adverse weather conditions and from sharp impacts. Once a year, the platform scale should be disassembled and cleaned. After reassembly, perform a multipoint calibration check.

7.2 Test Fuel Scale or Balance

The test fuel scale should be maintained according to the manufacturer's instructions. The wood storage area may not be a suitable place to store the test fuel balance because of the high humidity requirements there.

7.3 Moisture Meter

The contact pins should be cleaned according to the recommendations of the manufacturer. Battery terminal connectors can become corroded after prolonged use. Clean terminals with a suitable wire brush. Contact grease can help reduce corrosion buildup.

7.4 Anemometer

The moving parts of a vane or propeller anemometer should be lubricated with light machine oil when calibrated or as needed.

7.5 Manometer

Check to ensure there is no discoloration or visible matter in the fluid. Once a year, the instrument should be disassembled, cleaned, and filled with fresh fluid.

7.6 Pumps

Several types of pumps are used in commercial sampling trains. Two of the most common are the fiber vane pump with in-line oiler and the diaphragm pump.

The fiber vane pump requires a periodic check of the oil and the oiler jar. The used oil (usually 10W nondetergent or machine weight) should be essentially the same translucent color as the unused or spare oil, and the jar should be no less than half full and leak free. When the fiber vane pump starts to run erratically or when the head is removed semiannually, the fiber vanes should be replaced.

The diaphragm pump requires little maintenance. If the pump runs erratically, it is normally because of a bad diaphragm or malfunctions in the valves. These parts are easily replaced and should be cleaned semiannually by complete disassembly of the train.

7.7 Rotameter

A rotameter should be disassembled and cleaned according to the manufacturer's instructions with the recommended cleaning fluids semiannually or more often if erratic behavior occurs.

7.8 Orsat Analyzer

Little periodic maintenance is required for the Orsat apparatus other than visual checks of the glassware, tubes, and expansion bulbs. Keep the valves closed during storage and avoid freezing temperatures. If the Orsat is to be stored over an extended period, it is generally better to remove all of the absorbing reagents. The flexible bags are generally subjected to extensive wear and require repair or replacement when leaks occur. Pay particular attention to the valves in the manifold since they tend to freeze up if contaminated by the absorbing solution.

7.9 Instrumental Analyzers

The instrumental gas analyzers come with manuals that specify maintenance procedures and how often each should be performed. Generally, this is monthly. Follow the manufacturer's recommendations and call an experienced field service representative if internal adjustments are needed. In addition, the user should refer to "Continuous Emission Monitoring Systems (CEMS) Good Operating Practices," Section 3.0.9 of Reference 6.

7.10 Other Sampling Train Components

All other sampling train components (probe, flexible bag, etc.) should be visually checked quarterly and completely disassembled and cleaned or replaced yearly. Many of the items (e.g., quick disconnects) should be replaced when damaged rather than checked periodically. Normally, the best procedure is to replace a component.

TABLE 7.1. ACTIVITY MATRIX: EQUIPMENT MAINTENANCE CHECKS

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Platform scale	No erratic behavior	Disassemble and clean yearly	Replace parts as needed, recalibrate
Test fuel scale or balance	No erratic behavior	Inspect semiannually	Replace parts as needed, recalibrate
Moisture meter	No damage	Inspect visually semiannually	Clean contacts, replace parts as needed
Anemometer	No damage; parts move freely	Inspect visually semiannually	Repair or replace parts as necessary, recalibrate
Manometer	Clean; no damage	Inspect semiannually; disassemble and clean yearly	Replace parts as needed
Orsat glassware, connecting tubing, expansion bulbs	No damage	Visually check before each use	Replace if damaged
Flexible bags	No damage	Visually check; leak check before each use	Repair or replace as required
Fiber vane pump	In-line oiler free of leaks and at least half full	Periodic check of oil and oiler jar; remove head and change fiber vanes yearly	Replace or refill oiler jar as needed

TABLE 7.1. ACTIVITY MATRIX: EQUIPMENT MAINTENANCE CHECKS (Continued)

Apparatus	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Diaphragm pump	Leak-free valves; diaphragm functioning properly	Clean valves during yearly disassembly or upon erratic behavior	Replace if cleaning will not correct the malfunction
Rotameter	Clean; no erratic behavior	Clean by manufacturer's recommendations yearly or upon erratic behavior	Replace
Instrumental analyzers	Clean; no erratic behavior	Follow manufacturer's recommendations	Call service representative for expert repair
Sampling train components	No damage; no erratic behavior	Visually check every 3 months; completely disassemble and clean or replace yearly	Repair or replace with spare component if in the field

8.0 AUDITING PROCEDURES

This section outlines recommended audits for ensuring the quality of the Method 28A measurements. Although not part of the auditing procedures, routine quality control checks by a testing team are necessary to consistently obtain quality data. An audit is different in that it is an independent assessment of the accuracy of data. Independence is achieved by having the audit made by an operator other than the one conducting the routine measurements and by using audit reference standards and equipment different from those routinely used in monitoring. The auditing procedures should include a performance evaluation of the individual measurement system components, as well as an evaluation of the total measurement system. The performance audit is a quantitative verification of the results, while the systems audit is a qualitative review of the measurement system. The performance audit and the systems audit are described in Sections 8.1 and 8.2. An activity matrix summarizing the auditing procedures is presented in Table 8.1 at the end of this section.

8.1 Performance Audits

Performance audits are conducted by the auditor to quantitatively assess the quality of data produced by the measurement system components (sample collection, sample analysis, and data processing). It is recommended that these audits be performed by the responsible control agency once during every test.

8.1.1 Audit of Analytical Phase Using Certified Gas Mixtures - Analyzer operation and operator technique can be checked by providing audit samples of certified gas mixtures to be analyzed prior to or along with field samples. One sample should contain concentrations of 2-4% CO_2 and about 15% O_2.

For an Orsat audit, these gas samples can be transferred from their pressurized storage containers to flexible bags and delivered to the test team on site by the auditor. However, it is better to operate sampling and analytical sample trains in their normal sampling mode (i.e., pass the audit gas through all filter, scrubbers, conditioners, and other analyzer components used during normal sampling and as much of the sampling probe as is practical). Replicate samples of the audit gas containing O_2, CO, and CO_2 concentrations similar to the concentrations expected during the test and one sample of zero gas should be sufficient for audit of the analytical phase.

The error of the analytical phase can be calculated as follows, and should be $\leq$0.5 percent for CO, CO_2, and O_2.

$$D = \overline{\%V_a} - \%V_c \qquad \text{Equation 8.1}$$

where:

D = Difference in the field test results and the certified audit value, %;

$\overline{\%V_a}$ = Field team's value as the average of at least three replicates, %; and

$\%V_c$ = Certified value of audit gas, %.

The results of the calculated %D should be included in the test record as an assessment of accuracy of the analytical phase.

Use audit gases that have been certified by comparison to NBS-SRMs or gas manufacturers' CRM following EPA Traceability Protocol No. 1. Refer to "Procedure for NBS-Traceable Certification of Compressed Gas Working Standards Used for Calibration and Audit of Continuous Source Emission Monitoring" in Section 3.0.4 of Reference 6. As an alternative to Protocol No. 1 audit gases, CRMs may be used directly as audit gases. A list of gas manufacturers that have prepared approved CRMs is available from EPA at the following address:

U. S. Environmental Protection Agency
Quality Assurance Division (MD-77)
Research Triangle Park, North Carolina 27711
Attn: List of CRM Manufacturers

If the audit indicates that the analyzer is out of tolerance, corrective action must be taken.

8.1.2 Audit of Process Measurement Equipment and Procedures - The components of the measurement system that require audits include the platform scale and fuel moisture meter, as well as the methods for determining usable firebox volume and for processing data. An audit should be performed for each of these system components once during every test. The auditing procedures for each of these components follow.

8.1.2.1 Platform Scale - An independent audit of the platform scale should be performed with at least three standard weights that have been certified by the NBS. The audit should be performed with the wood heater and flue pipe assembly installed on the platform scale to determine if the scale is capable of accurately measuring the weight changes of the test fuel. The flue pipe assembly should not interfere with the performance of the platform scale. The three standard weights should span the weight changes of the test fuel during a test run. One of the standard weights should be approximately the weight of a full test load, the second should be approximately half the weight of a test load, and the third should be 1 kg. The audit should be performed either during the pretest burn period or immediately following the test run. During the audit, the bottom surface temperature of the wood heater should be recorded and compared to the maximum operating temperature of the scale.

8.1.2.2 Fuel Moisture Meter - The accuracy of the fuel moisture meter is checked by comparing the meter's readings to the amount of moisture that evaporates during oven drying. This comparison is done by first measuring the moisture content of three test fuel pieces with the moisture meter. Then the same three test fuel pieces should be oven dried and the moisture content determined by using the procedures outlined in Section 2.8.3. The results of the independent measurements should be compared and, if there is any disagreement, the moisture meter should be recalibrated.

8.1.2.3 Firebox Volume Measurement - The audit of the firebox volume measurement consists of an independent determination of the usable firebox volume. It is recommended that the audit be performed before emissions sampling to ensure that the weight of the test fuel load is correct. When performing the audit, the auditor should measure the firebox dimensions and determine the usable firebox volume independently of the testing team, using the procedures in Section 3.1. The results of the audit should be compared to the firebox volume calculated by the testing team. If the audit yields a disagreement greater than 5%, the firebox volume should be determined again using common dimensions and calculations as agreed upon by both the auditor and testing team.

8.1.3 Data Processing - The data recorded on the field and laboratory forms should be inspected for unusual data points or errors. A complete set of calculation should be performed by the auditor to ensure that burn rate and air-to-fuel ratios were determined correctly. If computer software is used to perform calculations, sample data should be entered into the programs. Results using the sample data should then be hand calculated and compared to the results generated by the computer. If disagreement results, the software should be corrected as necessary.

8.2 Systems Audit

A systems audit is an on-site qualitative inspection and review of the total measurement system (process measurement, data processing, etc.). When a new laboratory is set up, a systems audit is recommended for each certification test until the measurement procedures become familiar.

The functions of the auditor are summarized in the following:

1. Observe procedures and techniques of the field team during sample collection.
2. Check/verify the records of apparatus calibration and the quality control charts used in the laboratory analysis.

3. Record the results of the audit and forward them with comments on source team management to the quality assurance coordinator so that any needed corrective actions may be implemented.

The auditor should observe the field team's overall performance of the source test. Specific operations to observe should include, but not be limited to the following:

1. Setting up and leak testing the sampling system
2. Use of zero and span gases
3. Purging of sampling train with stack gas prior to collecting the sample
4. Sampling rate (constant)
5. Transferring of the sample from the collapsible bag to the Orsat analyzer and sample recovery.

Figure 8.1 is a suggested checklist form for use by the auditors in developing their own list of important techniques or steps to observe.

The EPA conducts an annual systems audit at test laboratories seeking accreditation. Manufacturers may request to be included in the EPA systems audit or alternatively may hire an accredited laboratory to perform this function.

Yes	No	Comment	Operation
			Presampling Preparations
			1. Knowledge of process conditions
			2. Traceability of calibration gas established
			3. Calibration of pertinent equipment
			On-Site Measurements
			4. Leak test of sampling train
			5. Analyzer warm-up per manufacturer's recommendations (if applicable)
			6. Purging the train prior to sampling
			7. Constant rate sampling
			8. Frequency of zero and span checks
			9. Drying agents and filters checked and replaced frequently
			Post-Sampling
			10. Transfer and handling of sample (if applicable)
			11. Data reduction procedure/check
			12. Calibration checks

General Comments

Figure 8.1. Checklist to be Used by Auditors

TABLE 8.1. ACTIVITY MATRIX FOR AUDITING PROCEDURES

Audit	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements Are Not Met
Analytical audit	$\%D = \overline{\%V_a} - \%V_c$ $\overline{\%V_a}$ = mean value of measurements by field team $\%V_c$ = certified value of audit gas $\%D \leq 0.5$ for each gas	As designated by the administrator	Advise team of sources of errors and request they seek additional training; rerun test if necessary for determination of compliance
Data processing audit	Agreement of original and check calculations	Once during each enforcement source test; independent calculations starting with raw data	Check and correct all data
Systems audit	Technique described in this section	Once during each enforcement test until experience gained, then every fourth test; observe techniques; use audit checklist, Figure 8.1	Explain the deviations from recommended techniques noted on Figure 8.1 to the team

9.0 RECOMMENDED STANDARDS FOR ESTABLISHING TRACEABILITY

To achieve data of desired quality, two considerations are necessary:

1. The measurement process must be in a state of statistical control.
2. The systematic errors, when combined with the random variations (errors of measurement), must result in an acceptably small uncertainty.

To ensure good data, it is necessary to perform quality control checks and independent audits of the measurement process; to document the data by quality control charts (as appropriate); and to use materials, instruments, and procedures that can be traced to a standard of reference.

Data must be routinely obtained by repeat measurements of standard reference samples, primary, secondary, and/or working standards. The working calibration standards should be traceable to primary or higher level standards such as the three listed below.

1. A wet test meter (2-L/min capacity) with a ±1% accuracy verified by liquid displacement.
2. NBS-SRM gases and gas manufacturers' CRM gases are considered primary standards.
3. Class F calibration weights certified to NBS standards.

9.1 Traceability Protocol for Establishing True Concentration of Gases Used for Calibration and Audit

The traceability protocol described in this section is intended to minimize systematic and random errors during the analysis of calibration and audit gas standards and to establish the true concentrations by means of NBS-SRMs, certified reference materials, or other NBS traceable gases.

Calibration gases are used to verify correct operator procedures and system integrity for the Orsat analysis method. Additionally, extractive continuous monitoring systems for gaseous pollutants must be calibrated and audited by using gas standards that are accurate and stable. Traceability requires direct comparisons between the calibration and audit gas standards and either an NBS-SRM or a certified reference material or a gas manufacturer's primary standard (GMPS) which is referenced to a NBS-SRM. All comparisons are made with an instrument calibrated with applicable NBS-SRMs. Traceability must be performed by the gas standard manufacturer at the time of purchase. Reanalysis to verify traceability may be performed by the gas standard manufacturer or by the user.

9.2 Establishing Traceability of Commercial Cylinder Gases to NBS-SRM Cylinder Gases

The following procedures for periodic multipoint calibrations and daily instrument span checks are prescribed to minimize systematic errors. Separate procedures for instrument span checks are described for linear and nonlinear instruments. To be linear, the difference between the concentrations indicated by the calibration curve and the straight line drawn from the point determined by the zero gas to the highest point determined by calibration must not exceed 2% of full scale at any point on the curve.

9.2.1 Multipoint Calibration - A multipoint calibration curve should be prepared monthly by using two SRM cylinder gases and the zero gas. The zero gas must contain $\leq$0.2% of the full-scale concentration of the component being analyzed, and it must be free of any impurity that will cause a response on the analytical instrument.

Multipoint calibration is accomplished by using a calibration flow system to dilute the SRM of highest concentration with the zero gas.

1. Read the responses for six points displaced from 0 to 100% of the instrument's full scale.

2. Plot the data and draw the calibration curve.
3. Read the response for the SRM of lower concentration without dilution.
4. Compare the apparent concentrations from the calibration curve to the true concentration of the lower SRM. Note: If the difference between the apparent and the true is >3% of the true concentration, repeat the multipoint calibration procedure.
5. Test the calibration curve for linearity. Proceed to either Section 9.2.2 or 9.2.3 for linear or nonlinear responses, respectively.

9.2.2 Instrument Span Check for Linear Responses - The span check should be performed at the start of each day that cylinder gases are to be analyzed.

1. Read the instrument's response to the highest SRM (or GMPS) in the range to be used and check the response to the zero gas.
2. Adjust the response to the value obtained in the most recent multipoint calibration and proceed to Section 9.3. Note: Cylinder gases analyzed with a linear instrument must not have a concentration >15% above the highest available SRM concentration.

9.2.3 Instrument Span Check for Nonlinear Response - The span check should be performed at the start of each day that cylinder gases are to be analyzed.

1. Read the instrument's responses to two SRMs (or GMPSs) in the range of calibration gases to be analyzed, and check responses to zero gas.
2. Set the instrument's zero with the zero gas and adjust its response to the highest SRM (or GMPS) to the value obtained in the most recent multipoint calibration.
3. Read the response to the lower SRM (or GMPS). Note: If the response to the lower SRM (or GMPS) varies by >3% from the response in the most recent multipoint calibration, a full multipoint calibration must be performed (Section 9.2.1). Otherwise, proceed to Section 9.3. Calibration gases analyzed with a nonlinear instrument must not have a concentration greater than the highest available SRM concentration.

9.3 Determining True Concentrations of Cylinder Gases

Direct comparison of the cylinder gas to an SRM (or a GMPS) should compensate for variations in instrument responses between the daily span check and the analyses. Significant variations in responses often result from changes in room temperature, line voltage, and so forth. Analyses in this procedure should be performed in triplicate (three pairs) to expose erroneous data points and excessive random variations in instrument response.

After the gas cylinder has been filled, wait a minimum of four days before beginning the following procedure. If necessary, adjust the instrument span prior to the analyses, but do not adjust it during the triplicate analyses.

1. Compare each cylinder gas directly with the nearest SRM (or GMPS) by taking alternate readings of the SRM and calibration gas responses in triplicate. Note: The response to zero gas must be read frequently so that the change in successive zero responses are not >1% of full scale.

2. For each of the six readings, determine the apparent concentration of the SRM (or GMPS) or cylinder gas by referring to the calibration curve.

3. For each pair of readings, one SRM (or GMPS) and one cylinder gas, calculate the true concentration of the cylinder gas by using Equation 9.1.

   True concentration of cylinder gas = Equation 9.1

   $$\left[\begin{array}{c}\text{apparent concen.} \\ \text{of cylinder gas}\end{array}\right] \times \left[\frac{\text{true concentration of SRM (or GMPS)}}{\text{apparent concentration of SRM (or GMPS)}}\right]$$

4. Determine the mean of the three values to get the true concentration of the cylinder gas. Note: If any one of the three values differs from the mean by >1.5%, discard the data, reset the instrument span (if necessary), and repeat Steps 1 through 4.

9.4 Using Gas Manufacturer's Primary Standards

Gas manufacturer's primary standards are gas mixtures prepared in pressurized containers and analyzed against SRM cylinder gases. Using GMPSs instead of SRMs will help to conserve SRMs where large quantities of cylinder gases are analyzed. A GMPS may be used for instrument span checks (Sections 9.2.2 and 9.2.3) and for cylinder gas analyses (Section 9.3) if the following conditions are met.

1. A GMPS must have been analyzed against SRM cylinder gases as described in Sections 9.2 and 9.3 within 30 days of their use for cylinder gas analysis, and should be compared on the days that instrument multipoint calibrations are performed.
2. A GMPS must not have changed in concentration by >1% per month (average) for the 3-month period prior to use for cylinder gas analysis.

In no case may a GMPS be substituted for an SRM in multipoint calibrations (Section 9.2.1).

9.5 Verifying Cylinder Gas Stability

The stability of each cylinder gas should be verified by a second set of triplicate analyses (using the procedure in Section 9.3), within 7 days after the first set of triplicate analyses. The mean of the second triplicate analyses must not differ from the mean of the first triplicate analysis by >1.5%.

9.6 Reanalyzing Cylinder Gases

Either the gas manufacturer or the user must reanalyze the cylinder gas every 6 months from the last analysis date by the procedure in Section 9.3. Cylinder gases used for audits may need to be analyzed more often than every 6 months.

9.7 Minimum Cylinder Pressure

No cylinder gas with pressure <200 psi, as shown by the cylinder gas regulator gauge, should be used.

9.8 Labeling the Cylinder and Preparing the Analysis Report

Each gas cylinder should have the following minimum traceability information either on a gummed label affixed to the cylinder wall or on a tag attached to the cylinder valve:

1. Cylinder number;
2. Mean concentration of cylinder gas, ppm, or mole percent;
3. Balance gas used;
4. Last analysis date; and
5. Expiration date (6 months after last analysis date for reactive gases and 12 months after for diluent gases).

A written analysis report certifying that the cylinder gas has been analyzed according to the protocol described in this section should contain the following information:

1. Cylinder number;
2. Mean concentration of cylinder gas (ppm or mole percent) on last analysis date;
3. Replicate analysis data;
4. Balance gas used;
5. Numbers of NBS-SRMs used;
6. Analytical principle used; and
7. Last analysis date.

The user should maintain a file of all analysis reports for 3 years.

9.9 Conducting Performance Audits

The U. S. Environmental Protection Agency (EPA) will initiate a national performance audit program of cylinder gases prepared by this protocol. Cylinder gases prepared following the protocol will be obtained (directly or indirectly) by EPA and analyzed in their laboratory for accuracy compared to the gas manufacturer's reported concentration.

10.0 REFERENCE METHOD

This section contains Method 28A as published in the Federal Register, Volume 53, Number 38 (February 26, 1988), page 5911, et seq. Additionally, Method 28 and Method 5H are included for reference. We recommend that the user also consult EPA Methods 3 and 5.

Method 28A—Measurement of Air To Fuel Ratio and Minimum Achievable Burn Rates For Wood-Fired Appliances

1. Applicability and Principle

1.1 Applicability. This method is applicable for the measurement of air to fuel ratios and minimum achievable burn rates, for determining whether a wood-fired appliance is an affected facility, as specified in 40 CFR 60.530.

1.2 Principle. A gas sample is extracted from a location in the stack of a wood-fired appliance while the appliance is operating at a prescribed set of conditions. The gas sample is analyzed for percent carbon dioxide (CO_2), percent oxygen (O_2), and percent carbon monoxide (CO). These stack gas components are measured for determining dry molecular weight of exhaust gas. Total moles of exhaust gas are determined stoichiometrically. Air to fuel ratio is determined by relating the mass of dry combustion air to the mass of dry fuel consumed.

2. Definitions

2.1 Burn Rate, Firebox, Secondary Air Supply, Test Facility, Test Fuel Charge, Test Fuel Crib, Test Fuel Loading Density, Test Fuel Piece, Test Run, Usable Firebox Volume, and Wood Heater. Same as Method 28, Sections 2.1 and 2.3 to 2.12.

2.2 Air to Fuel Ratio. Ratio of the mass of dry combustion air introduced into the firebox, to the mass of dry fuel consumed (grams of dry air per gram of dry wood burned).

3. Apparatus

3.1 Test Facility, Insulated Solid Pack Chimney, Platform Scale and Monitor, Room Temperature Monitor, Balance, Moisture Meter, Anemometer, Barometer, Draft Gauge, and Humidity Gauge. Same as Method 28, Sections 3.1, 3.2, and 3.4 to 3.10, respectively.

3.2 Sampling System. Probe, Condenser, Valve, Pump, Rate Meter, Flexible Bag, Pressure Gauge, and Vacuum Gauge. Same as Method 3, Sections 2.2.1 to 2.2.8, respectively. The sampling systems described in Method 5H, Sections 2.2.1, 2.2.2, and 2.2.3, may be used.

3.3 Analysis. Orsat analyzer, same as Method 3, Section 2.3; or instrumental analyzers, same as Method 5H, Sections 2.2.4 and 2.2.5, for CO_2 and CO analyzers, except use a CO analyzer with a range of 0 to 5 percent and use a CO_2 analyzer with a range of 0 to 5 percent. Use an O_2 analyzer capable of providing a measure of O_2 in the range of 0 to 25 percent by volume at least once every 10 minutes. Prepare cylinder gases for the three analyzers as described in Method 5H, Section 3.3.

4. Test Preparation

4.1 Test Facility, Wood Heater Appliance Installation, and Test Facility Conditions. Same as Method 28, Sections 4.1.1 and 4.1.2, respectively, with the exception that barometric dampers or other devices designed to introduce dilution air downstream of the firebox shall be sealed.

4.2 Wood Heater Air Supply Adjustments. This section describes how dampers are to be set or adjusted and air inlet ports closed or sealed during Method 28A tests. The specifications in this section are intended to ensure that affected facility determinations are made on the facility configurations that could reasonably be expected to be employed by the user. They are also intended to prevent circumvention of the standard through the addition of an air port that would often be blocked off in actual use. These specifications are based on the assumption that consumers will remove such items as dampers or other closure mechanism stops if this can be done readily with household tools; that consumers will block air inlet passages not visible during normal operation of the appliance using aluminum tape or parts generally available at retail stores; and that consumers will cap off any threaded or flanged air inlets. They also assume that air leakage around glass doors, sheet metal joints or through inlet grilles visible during normal operation of the appliance would not be further blocked or taped off by a consumer.

It is not the intention of this section to cause an appliance that is clearly designed, intended, and, in most normal installations, used as a fireplace to be converted into a wood heater for purposes of applicability testing. Such a fireplace would be identifiable by such features as large or multiple glass doors or panels that are not gasketed, relatively unrestricted air inlets intended, in large part, to limit smoking and fogging of glass surfaces, and other aesthetic features not normally included in wood heaters.

4.2.1 Adjustable Air Supply Mechanisms. Any commercially available flue damper, other adjustment mechanism or other air inlet port that is designed, intended or otherwise reasonably expected to be adjusted or closed by consumers, installers, or dealers and which could restrict air into the firebox shall be set so as to achieve minimum air into the firebox, i.e., closed off or set in the most closed position.

Flue dampers, mechanisms and air inlet ports which could reasonably be expected to be adjusted or closed would include:

(a) All internal or externally adjustable mechanisms (including adjustments that affect the tightness of door fittings) that are accessible either before and/or after installation.

(b) All mechanisms, other inlet ports, or inlet port stops that are identified in the owner's manual or in any dealer literature as being adjustable or alterable. For example, an inlet port that could be used to provide access to an outside air duct but which is identified as being closable through use of additional materials whether or not they are supplied with the facility.

(c) Any combustion air inlet port or commercially available flue damper or mechanism stop, which would readily lend itself to closure by consumers who are handy with household tools by the removal of parts or the addition of parts generally available at retail stores (e.g., addition of a pipe cap or plug, addition of a small metal plate to an inlet hole on a nondecorative sheet metal surface, or removal of riveted or screwed damper stops).

(d) Any flue damper, other adjustment mechanisms or other air inlet ports that are found and documented in several (e.g., a number sufficient to reasonably conclude that the practice is not unique or uncommon) actual installations as having been adjusted to a more closed position, or closed by consumers, installers, or dealers.

4.2.2 Air Supply Adjustments During Test. The test shall be performed with all air inlets identified under this section in the closed or most closed position or in the configuration which otherwise achieves the lowest air inlet (e.g., greatest blockage).

For the purposes of this section, air flow shall not be minimized beyond the point necessary to maintain combustion or beyond the point that forces smoke into the room

Notwithstanding Section 4.2.1, any flue damper, adjustment mechanism or air inlet port (whether or not equipped with flue dampers or adjusting mechanisms) that is visible during normal operation of the appliance and which could not reasonably be closed further or blocked except through means that would significantly degrade the aesthetics of the facility (e.g., through use of duct tape) will not be closed further or blocked.

4.3 Test Fuel Properties and Test Fuel Charge Specifications. Same as Method 28, Sections 4.2 to 4.3, respectively.

4.4 Sampling System.

4.4.1 Sampling Location. Same as Method 5H, Section 5.1.2.

4.4.2 Sampling System Set Up. Set up the sampling equipment as described in Method 3, Section 3.2, or as in Method 3A, Section 7.

5. Procedures

5.1 Pretest Preparation. Same as Method 28, Sections 6.2.1 and 6.2.3 to 6.2.5.

5.2 Pretest Ignition. Same as Method 28, Section 6.3. Set the wood heater air supply settings to achieve a burn rate in Category 1 or the lowest achievable burn rate (see Section 4.2).

5.3 Test Run. Same as Method 28, Section 6.4. Begin sample collection at the start of the test run as defined in Method 28, Section 6.4.1. If Method 3 is used, collect a minimum of two bag samples simultaneously at a constant sampling rate for the duration of the test run. A minimum sample volume of 30 l per bag is recommended. If instrumental gas concentration measurement procedures are used, conduct the gas measurement system performance specifications checks as described in Method 5H, Sections 6.7, 6.8, and 6.9. The zero drift and calibration drift limits for all three analyzers shall be 0.2 percent O_2, CO_2, or CO, as applicable, or less. Other measurement system performance specifications are as defined in Method 5H, Section 4. Sample at a constant rate for the duration of the test run.

5.3.1 Data Recording. Record wood heater operational data, test facility temperature, sample train flow rate, and fuel weight data at 10-minute intervals.

5.3.2 Test Run Completion. Same as Method 28, Section 6.4.6.

5.4 Analysis Procedure.

5.4.1 Method 3 Integrated Bag Samples. Within 4 hours after the sample collection, analyze each bag sample for percent CO_2, O_2, and CO using an Orsat analyzer as described in Method 3, Sections 4.2.5 through 4.2.7.

5.4.2 Instrumental Analyzers. Average the percent CO_2, CO, and O_2 values for the test run.

5.5 Quality Control Procedures.

5.5.1 Data Validation. The following quality control procedure is suggested to provide a check on the quality of the data.

5.5.1.1 Calculate a fuel factor, F_o, using the following equation:

$$F_o = \left(\frac{20.9 - \%\,O_2}{\%\,CO_2}\right) \quad \text{Eq. 28a-4}$$

where:

$\%O_2$ Percent O_2 by volume (dry basis).
$\%CO_2$ Percent CO_2 by volume (dry basis).
20.9 Percent O_2 by volume in ambient air.

If CO is present in quantities measurable by this method, adjust the O_2 and CO_2 values before performing the calculation for F_o as follows:

$\%CO_2\ (adj) = \%CO_2 + \%CO$
$\%O_2\ (adj) = \%O_2 - 0.5\ \%CO$

where:

%CO = Percent CO by volume (dry basis).

5.5.1.2 Compare the calculated F_o factor with the expected F0 range for wood (1.000 - 1.120). Calculated F0 values beyond this acceptable range should be investigated before accepting the test results. For example, the strength of the solutions in the gas analyzer and the analyzing technique should be checked by sampling and analyzing a known concentration, such as air. If no detectable or correctable measurement error can be identified, the test should be repeated. Alternatively, determine a range of air to fuel ratio results that could include the correct value by using an F_o value of 1.05 and calculating a potential range of CO_2 and O_2 values. Acceptance of such results will be based on whether the calculated range includes the exemption limit and the judgment of the administrator.

5.5.1.3 Method 3 Analyses. Compare the results of the analyses of the two bag samples. If all the gas components (O_2, CO, and CO_2) values for the two analyses agree within 0.5 percent (e.g., 6.0 percent O_2 for bag 1 and 6.5 percent O_2 for bag 2, agree within 0.5 percent), the results of the bag analyses may be averaged for the calculations in Section 6. If the analysis results do not agree within 0.5 percent for each component, calculate the air-to-fuel ratio using both sets of analyses and report the results.

6. Calculations

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figure after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

6.1 Nomenclature.

M_d = Dry molecular weight, g/g-mole(lb/lb-mole).
$\%CO_2$ = Percent CO_2 by volume (dry basis).
$\%O_2$ = Percent O_2 by volume (dry basis).
%CO = Percent CO by volume (dry basis).
$\%N_2$ = Percent N_2 by volume (dry basis).
N_T = Total gram-moles of dry exhaust gas per kg of wood burned (lb-moles/lb).
Y_{CO2} = Measured mole fraction of CO_2 (e.g., 10 percent CO_2 = .10 mole fraction), g/g-mole (lb/lb-mole).
Y_{CO} = Measured mole fraction of CO (e.g., 1 percent CO = .01 mole fraction), g/g-mole (lb/lb-mole).
Y_{HC} = Assumed mole fraction of HC (dry as CH_4)
= 0.0088 for catalytic wood heaters;
= 0.0132 for noncatalytic wood heaters;
= 0.0080 for pellet-fired wood heaters.
0.280 = Molecular weight of N_2 or CO, divided by 100.
0.320 = Molecular weight of O_2 divided by 100.
0.440 = Molecular weight of CO_2 divided by 100.
42.5 = Gram-moles of carbon in 1 kg of dry wood assuming 51 percent carbon by weight dry basis (.0425 lb/lb).
510 = Grams of carbon in exhaust gas per kg of wood burned.
1,000 = Grams in 1 kg.

6.2 Dry Molecular Weight. Use Equation 28a–1 to calculate the dry molecular weight of the stack gas.

$$M_d = 0.440(\%CO_2) + 0.320(\%O)_2) + 0.280(\%N_2 + \%CO) \quad \text{Eq. 28a-1}$$

Note: The above equation does not consider argon in air (about 0.9 percent, molecular weight of 37.7). A negative error of about 0.4 percent is introduced. The tester may opt to include argon in the analysis using procedures subject to approval of the Administrator.

6.3 Dry Moles of Exhaust Gas. Use Equation 28a–2 to calculate the total moles of dry exhaust gas produced per kilogram of dry wood burned.

$$N_T = \left(\frac{42.5}{(Y_{CO2} + Y_{CO} + Y_{HC})}\right) \quad \text{Eq. 28a-2}$$

6.4 Air to Fuel Ratio. Use Equation 28a–3 to calculate the air to fuel ratio on a dry mass basis.

$$A/f = \left(\frac{(N_T \times M_d)\quad(510)}{(1000)}\right) \quad \text{Eq. 28a-3}$$

6.5 Burn Rate. Calculate the fuel burn rate as in Method 28, Section 8.3.

7. Bibliography

Same as Method 3, Section 7, and Method 5H, Section 7.

4. By adding a new Appendix I as follows.

Method 5H—Determination of Particulate Emissions From Wood Heaters From a Stack Location

Applicability and Principle

1.1 Applicability. This method is applicable for the determination of particulate matter and condensible emissions from wood heaters.

1.2 Principle. Particulate matter is withdrawn proportionally from the wood heater exhaust and is collected on two glass fiber filters separated by impingers immersed in an ice bath. The first filter is maintained at a temperature of no greater than 120 °C (248 °F). The second filter and the impinger system are cooled such that the exiting temperature of the gas is no greater than 20 °C (68 °F). The particulate mass collected in the probe, on the filters, and in the impingers is determined gravimetrically after removal of uncombined water.

2. Apparatus

2.1 Sampling Train. The sampling train configuration is shown in Figure 5H-1. APTD-0576 is suggested for operating and maintenance procedures. The train consists of the following components:

2.1.1 Probe Nozzle. (Optional) Same as Method 5, Section 2.1.1. A straight sampling probe without a nozzle is an acceptable alternative.

2.1.2 Probe Liner. Same as Method 5, Section 2.1.2, except that the maximum length of the sample probe shall be 0.6 m (2 ft) and probe heating is optional.

2.1.3 Differential Pressure Gauge. Same as Method 5, Section 2.1.4.

2.1.4 Filter Holders. Two each of borosilicate glass, with a glass frit or stainless steel filter support and a silicone rubber, Teflon, or Viton gasket. The holder design shall provide a positive seal against leakage from the outside or around the filter. The front filter holder shall be attached immediately at the outlet of the probe and prior to the first impinger. The second filter holder shall be attached on the outlet of the third impinger and prior to the inlet of the fourth (silica gel) impinger.

Note: Mention of trade names or specific product does not constitute endorsement by the Environmental Protection Agency.

2.1.5 Filter Heating System. Same as Method 5, Section 2.1.6.

2.1.6 Condenser. Same as Method 5, Section 2.1.7, used to collect condensible materials and determine the stack gas moisture content.

2.1.7 Metering System. Same as Method 5, Section 2.1.8.

2.1.8 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg).

2.2 Stack Flow Rate Measurement System. A schematic of an example test system is shown in Figure 5H-2. The flow rate measurement system consists of the following components:

2.2.1 Sample Probe. A glass or stainless steel sampling probe.

2.2.2 Gas Conditioning System. A high density filter to remove particulate matter and a condenser capable of lowering the dew point of the gas to less than 5 °C (40 °F). Desiccant, such as Drierite, may be used to dry the sample gas. Do not use silica gel.

2.2.3 Pump. An inert (i.e., Teflon or stainless steel heads) sampling pump capable of delivering more than the total amount of sample required in the manufacturer's instructions for the individual instruments. A means of controlling the analyzer flow rate and a device for determining proper sample flow rate (e.g., precision rotameter, pressure gauge downstream of all flow controls) shall be provided at the analyzer. The requirements for measuring and controlling the analyzer flow rate are not applicable if data are presented that demonstrate the analyzer is insensitive to flow variations over the range encountered during the test.

2.2.4 CO Analyzer. Any analyzer capable of providing a measure of CO in the range of 0 to 10 percent by volume at least once every 10 minutes.

2.2.5 CO_2 Analyzer. Any analyzer capable of providing a measure of CO_2 in the range of 0 to 25 percent by volume at least once every 10 minutes.

Note: Analyzers with ranges less than those specified above may be used provided actual concentrations do not exceed the range of the analyzer.

2.2.6 Manifold. A sampling tube capable of delivering the sample gas to two analyzers and handling an excess of the total amount used by the analyzers. The excess gas is exhausted through a separate port.

2.2.7 Recorders (optional). To provide a permanent record of the analyzer outputs.

2.3 Proportional Gas Flow Rate System. To monitor stack flow rate changes and provide a measurement that can be used to adjust and maintain particulate sampling flow rates proportional to the stack flow rate. A schematic of the proportional flow rate system is shown in Figure 5H-2 and consists of the following components:

2.3.1 Tracer Gas Injection System. To inject a known concentration of SO_2 into the flue. The tracer gas injection system consists of a cylinder of SO_2, a gas cylinder regulator, a stainless steel needle valve or flow controller, a nonreactive (stainless steel and glass) rotameter, and an injection loop to disperse the SO_2 evenly in the flue.

2.3.2 Sample Probe. A glass or stainless steel sampling probe.

2.3.3 Gas Conditioning System. A combustor as described in Method 16A, Sections 2.1.5 and 2.1.6, followed by a high density filter to remove particulate matter, and a condenser capable of lowering the dew point of the gas to less than 5 °C (40 °F). Desiccant, such as Drierite, may be used to dry the sample gas. Do not use silica gel.

2.3.4 Pump. As described in Section 2.2.3.

2.3.5 SO_2 Analyzer. Any analyzer capable of providing a measure of the SO_2 concentration in the range of 0 to 1,000 ppm by volume (or other range necessary to measure the SO_2 concentration) at least once every 10 minutes.

2.3.6 Recorder (optional). To provide a permanent record of the analyzer outputs.

Note: Other tracer gas systems, including helium gas systems, are allowed for determining instantaneous proportional sampling rates.

2.4 Sample Recovery. Probe liner and probe nozzle brushes, wash bottles, sample storage containers, petri dishes, graduated cylinder or balance, plastic storage containers, funnel and rubber policeman, as described in Method 5, Sections 2.2.1 through 2.2.8, respectively, are needed.

2.5 Analysis. Weighing dishes, desiccator, analytical balance, beakers (250 ml or less), hygrometer or psychrometer, and temperature gauge as described in Method 5, Sections 2.3.1 through 2.3.7, respectively, are needed. In addition, a separatory funnel, glass or Teflon, 500 ml or greater, is needed.

3. Reagents

3.1 Sampling. The reagents used in sampling are as follows:

3.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency (<0.05 percent penetration) on 0.3-micron dioctyl phthalate smoke particles. Gelman A/E 61631 filters have been found acceptable for this purpose.

3.1.2 Silica Gel. Same as Method 5, Section 3.1.2.

3.1.3 Water. Deionized distilled to conform to ASTM Specification D1193–77, Type 3 (incorporated by reference—see § 60.17). Run blanks prior to field use to eliminate a high blank on test samples.

3.1.4 Crushed Ice.

3.1.5 Stopcock Grease. Same as Method 5, Section 3.1.5.

3.2 Sample Recovery. Same as Method 5, Section 3.2.

3.3 Cylinder Gases. For the purposes of this procedure, span value is defined as the upper limit of the range specified for each analyzer as described in Section 2.2 or 2.3. If an analyzer with a range different from that specified in this method is used, the span value shall be equal to the upper limit of the range for the analyzer used (see **Note** in Section 2.2.5).

3.3.1 Calibration Gases. The calibration gases for the CO_2, CO and SO_2 analyzers shall be CO_2, CO, or SO_2, as appropriate, in N_2. CO_2 and CO calibration gases may be combined in a single cylinder.

There are two alternatives for checking the concentrations of the calibration gases. (a) The first is to use calibration gases that are documented traceable to National Bureau of Standards Reference Materials. Use *Traceability Protocol for Establishing True Concentrations of Gases Used for Calibrations and Audits of Continuous Source Emission Monitors* (Protocol Number 1) that is available from the Environmental Monitoring and Support Laboratory, Quality Assurance Branch, Mail Drop 77, Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Obtain a certification from the gas manufacturer that the protocol was followed. These calibration gases are not to be analyzed with the test methods. (b) The second alternative is to use calibration gases not prepared according to the protocol. If this alternative is chosen, within 6 months prior to the certification test, analyze each of the CO_2 and CO calibration gas mixtures in triplicate using Method 3, and within 1 month prior to the certification test, analyze SO_2 calibration gas mixtures using Method 6. For the low-level, mid-level, or high-level gas mixtures, each of the individual SO_2 analytical results must be within 10 percent (or 10 ppm, whichever is greater) of the triplicate set average; CO_2 and CO test results must be within 0.5 percent CO_2 and CO; otherwise, discard the entire set and repeat the triplicate analyses. If the average of the triplicate test method results is within 5 percent for SO_2 gas (or 0.5 percent CO_2 and CO for the CO_2 and CO gases) of the calibration gas manufacturer's tag values, use the tag value; otherwise, conduct at least three additional test method analyses until the results of six individual SO_2 runs (the three original plus three additional) agree within 10 percent (or 10 ppm, whichever is greater) of the average (CO_2 and CO test results must be within 0.5 percent). Then use this average for the cylinder value. Four calibration gas levels are required as specified below:

3.3.1.1 High-level Gas. A gas concentration that is equivalent to 80 to 90 percent of the span value.

3.3.1.2 Mid-level Gas. A gas concentration that is equivalent to 45 to 55 percent of the span value.

3.3.1.3 Low-level Gas. A gas concentration that is equivalent to 20 to 30 percent of the span value.

3.3.1.4 Zero Gas. A gas concentration of less than 0.25 percent of the span value. Purified air may be used as zero gas for the CO_2, CO, and SO_2 analyzers.

3.3.2 SO_2 Injection Gas. A known concentration of SO_2 in N_2. The concentration must be at least 2 percent SO_2 with a maximum of 100 percent SO_2. The cylinder concentration shall be certified by the manufacturer to be within 2 percent of the specified concentration.

3.4 Analysis. Three reagents are required for the analysis:

3.4.1 Acetone. Same as 3.2.

3.4.2 Dichloromethane (Methylene Chloride). Reagent grade, <0.001 percent residue in glass bottles.

3.4.3 Desiccant. Anhydrous calcium sulfate, calcium chloride, or silica gel, indicating type.

4. Gas Measurement System Performance Specifications.

4.1 Response Time. The amount of time required for the measurement system to display 95 percent of a step change in gas concentration. The response time for each analyzer and gas conditioning system shall be no more than 2 minutes.

4.2 Zero Drift. The zero drift value for each analyzer shall be less than 2.5 percent of the span value over the period of the test run.

4.3 Calibration Drift. The calibration drift value measured with the mid-level calibration gas for each analyzer shall be less than 2.5 percent of the span value over the period of the test run.

4.4 Resolution. The resolution of the output for each analyzer shall be 0.5 percent of span value or less.

4.5 Calibration Error. The linear calibration curve produced using the zero and mid-level calibration gases shall predict the actual response to the low-level and high-level calibration gases within 2 percent of the span value.

5. Procedure

5.1 Pretest Preparation.

5.1.1 Filter and Desiccant. Same as Method 5, Section 4.1.1.

5.1.2 Sampling Probe and Nozzle. The sampling location for the particulate sampling probe shall be 2.45±0.15 m (8±0.5 ft) above the platform upon which the wood heater is placed (i.e., the top of the scale).

Select a nozzle, if used, sized for the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain proportional sampling rates. During the run, do not change the nozzle size.

Select a suitable probe liner and probe length to effect minimum blockage.

5.1.3 Preparation of Particulate Sampling Train. During preparation and assembly of the particulate sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using a tweezer or clean surgical gloves, place one labeled (identified) and weighed filter in each of the filter holders. Be sure that each of the filters is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check the filters for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct.

Set up the train as in Figure 5H-1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD–0576) to avoid possibility of contamination by the silicone grease.

Place crushed ice around the impingers.

5.1.4 Leak-Check Procedures.

5.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, conduct the leak-check as described in Method 5, Section 4.1.4.1, except that a vacuum of 130 mm Hg (5 in. Hg) may be used instead of 380 mm Hg (15 in. Hg).

5.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, conduct a leak-check as described in Method 5, Section 4.1.4.2.

5.1.4.3 Post-Test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures described in Method 5, Section 4.1.4.3, except that a vacuum of 130 mm Hg (5 in. Hg) or the greatest vacuum measured during the test run, whichever is greater, may be used instead of 380 mm Hg (15 in. Hg).

5.1.5 Tracer Gas Procedure. A schematic of the tracer gas injection and sampling systems is shown in Figure 5H–2.

5.1.5.1 SO_2 Injection Probe. Install the SO_2 injection probe and dispersion loop in the stack at a location 2.8±0.15 m (9.5±0.5 ft) above the sampling platform.

5.1.5.2 SO_2 Sampling Probe. Install the SO_2 sampling probe at the centroid of the stack at a location 4±0.15 m (13.5±0.5 ft) above the sampling platform.

5.1.6 Flow Rate Measurement System. A schematic of the flow rate measurement system is shown in Figure 5H–2. Locate the flow rate measurement sampling probe at the centroid of the stack at a location 2.3±0.3 m (7.5±1 ft) above the sampling platform.

5.2 Test Run Procedures. The start of the test run is defined as in Method 28, Section 6.4.1.

5.2.1 Tracer Gas Procedure. Within 1 minute after closing the wood heater door at the start of the test run, meter a known concentration of SO_2 tracer gas at a constant flow rate into the wood heater stack. Monitor the SO_2 concentration in the stack, and record the SO_2 concentrations at 10-minute intervals or more often at the option of the tester. Adjust the particulate sampling flow rate proportionally to the SO_2 concentration changes using Equation 5H-6 (e.g., the SO_2 concentration at the first 10-minute reading is measured to be 100 ppm; the next 10 minute SO_2 concentration is measured to be 75 ppm; the particulate sample flow rate is adjusted from the initial 0.15 cfm to 0.20 cfm). A check for proportional rate variation shall be made at the completion of the test run using Equation 5H-10.

5.2.2 Volumetric Flow Rate Procedure. Apply stoichiometric relationships to the wood combustion process in determining the exhaust gas flow rate as follows:

5.2.2.1 Test Fuel Charge Weight. Record the test fuel charge weight in kilograms (wet) as specified in Method 28, Section 6.4.2. The wood is assumed to have the following weight percent composition: 51 percent carbon, 7.3 percent hydrogen, 41 percent oxygen. Record the wood moisture for each wood charge as described in Method 28, Section 6.2.5. The ash is assumed to have negligible effect on associated C, H, O concentrations after the test burn.

5.2.2.2 Measured Values. Record the CO and CO_2 concentrations in the stack on a dry basis every 10 minutes during the test run or more often at the option of the tester. Average these values for the test run. Use as a mole fraction (e.g., 10 percent CO_2 is recorded as 0.10) in the calculations to express total flow Equation 5H-7.

5.2.3 Particulate Train Operation. For each run, record the data required on a data sheet such as the one shown in Figure 5H-3. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak-check, and when sampling is halted. Take other readings as indicated on Figure 5H-3 at least once each 10 minutes during the test run.

Remove the nozzle cap, verify that the filter and probe heating systems are up to temperature, and that the probe is properly positioned. Position the nozzle, if used, facing into gas stream, or the probe tip in the 50 mm (2 in.) centroidal area of the stack.

Be careful not to bump the probe tip into the stack wall when removing or inserting the probe through the porthole; this minimizes the chance of extracting deposited material.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Begin sampling at the start of the test run as defined in Method 28, Section 6.4.1, start the sample pump, and adjust the sample flow rate to between 0.003 and 0.015 m^3/min (0.1 and 0.5 cfm). Adjust the sample flow rate proportionally to the stack flow during the test run (Section 5.2.1), and maintain a proportional sampling rate (within 10 percent of the desired value) and a filter holder temperature no greater than 120 °C (248 °F).

During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level. Add more ice to the impinger box and, if necessary, salt to maintain a temperature of less than 20 °C (68 °F) at the condenser/silica gel outlet.

If the pressure drop across the filter becomes too high, making sampling difficult to maintain, either filter may be replaced during a sample run. It is recommended that another complete filter assembly be used rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak-check (see Section 5.1.4.2). The total particulate weight shall include the summation of all filter assembly catches. The total time for changing sample train components shall not exceed 10 minutes. No more than one component change is allowed for any test run.

At the end of the test run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 5.1.4.3.

5.3 Sample Recovery. Begin recovery of the probe and filter sample as described in Method 5, Section 4.2, except that an acetone blank volume of about 50 ml may be used. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the front filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry Nylon bristle brush and/or a sharp-edged blade. Seal and label the container.

Container No. 2. Remove the filter from the back filter holder using the same procedures as described above.

Container No. 3. Same as Method 5, Section 4.2 for Container No. 2, except that descriptions of capping and sample transport are not applicable if sample recovery and analysis occur in the same room.

Container No. 4. Treat the impingers as follows: Measure the liquid which is in the first three impingers to within 1 ml by using a graduated cylinder or by weighing it to within 0.5 g by using a balance (if one is available). Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas.

Transfer the water from the first, second and third impingers to a glass container. Tighten the lid on the sample container so that water will not leak out. Rinse impingers and graduated cylinder, if used, with acetone three times or more. Avoid direct contact between the acetone and any stopcock grease or collection of any stopcock grease in the rinse solutions. Add these rinse solutions to sample Container No. 3.

Whenever possible, containers should be transferred in such a way that they remain upright at all times. Descriptions of capping and transport of samples are not applicable if sample recovery and analysis occur in the same room.

Container No. 5. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available, follow the procedure for Container No. 5 in Section 5.4.

5.4 Analysis. Record the data required on a sheet such as the one shown in Figure 5H-4. Handle each sample container as follows:

Containers No. 1 and 2. Leave the contents in the shipping container or transfer both of the filters and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for no more than 36 hours. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 5.6, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 2 hours between weighings.

Container No. 3. Note the level of liquid in the container and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Determination of sample leakage is not applicable if sample recovery and analysis occur in the same room. Measure the liquid in this container either volumetrically to within 1 ml or gravimetrically to within 0.5 g. Transfer the contents to a tared 250-ml or smaller beaker, and evaporate to dryness at ambient temperature and pressure. Desiccate and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 4. Note the level of liquid in the container and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Determination of sample leakage is not applicable if sample recovery and analysis occur in the same room. Measure the liquid in this container either volumetrically to within 1 ml or gravimetrically to within 0.5 g. Transfer the contents to a 500 ml or larger separatory funnel. Rinse the container with water, and add to the separatory funnel. Add 25 ml of dichloromethane to the separatory funnel, stopper and vigorously shake 1 minute, let separate and transfer the dichloromethane (lower layer) into a tared beaker or evaporating dish. Repeat twice more. It is necessary to rinse the Container No. 4 with dichloromethane. This rinse is added to the impinger extract container. Transfer the remaining water from the separatory funnel to a tared beaker or evaporating dish and evaporate to dryness at 220 °F (105 °C). Desiccate and weigh to a constant weight. Evaporate the combined impinger water extracts at ambient temperature and pressure. Desiccate and weigh to a constant weight. Report both results to the nearest 0.1 mg.

Container No. 5. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml or smaller beaker, and evaporate to dryness at ambient temperature and pressure. Desiccate and weigh to a constant weight. Report the results to the nearest 0.1 mg.

"Dichloromethane" Container. Measure 75 ml of dichloromethane in this container and treat it the same as the "acetone blank."

"Water Blank" Container. Measure 200 ml water into this container either volumetrically or gravemetrically. Transfer the water to a tared 250-ml beaker and evaporate to dryness at 105 °C (221 °F). Desiccate and weigh to a constant weight.

6. Calibration

Maintain a laboratory record of all calibrations.

6.1 Volume Metering System.

6.1.1 Initial and Periodic Calibration. Before the first certification or audit test and at least semiannually, thereafter, calibrate the volume metering system as described in Method 5G, Section 5.2.1.

6.1.2 Calibration After Use. Same as Method 5G, Section 5.2.2.

6.1.3 Acceptable Variation in Calibration. Same as Method 5G, Section 5.2.3.

6.2 Probe Heater Calibration. (Optional) The probe heating system shall be calibrated before the first certification or audit test. Use the procedure described in Method 5, Section 5.4.

6.3 Temperature Gauges. Use the procedure in Method 2, Section 4.3, to calibrate in-stack temperature gauges before the first certification or audit test and semiannually, thereafter.

6.4 Leak-Check of Metering System Shown in Figure 5H–1. That portion of the sampling train from the pump to the orifice meter shall be leak-checked after each certification or audit test. Use the procedure described in Method 5, Section 5.6.

6.5 Barometer. Calibrate against a mercury barometer before the first certification test and semiannually, thereafter. If a mercury barometer is used, no calibration is necessary. Follow the manufacturer's instructions for operation.

6.6 SO_2 Injection Rotameter. Calibrate the SO_2 injection rotameter system with a soap film flowmeter or similar direct volume measuring device with an accuracy of ± 2 percent. Operate the rotameter at a single reading for at least three calibration runs for 10 minutes each. When three consecutive calibration flow rates agree within 5 percent, average the three flow rates, mark the rotameter at the calibrated setting, and use the calibration flow rate as the SO_2 injection flow rate during the test run. Repeat the rotameter calibration before the first certification test and semiannually, thereafter.

6.7 Analyzer Calibration Error Check. Conduct the analyzer calibration error check prior to each certification test.

6.7.1 Calibration Gas Injection. After the flow rate measurement system and the tracer gas measurement system have been prepared for use (Sections 5.1.5.2 and 5.1.6), introduce zero gases and then the mid-level calibration gases for each analyzer. Set the analyzers' output responses to the appropriate levels. Then introduce the low-level and high-level calibration gases, one at a time, for each analyzer. Record the analyzer responses.

6.7.2 Acceptability Values. If the linear curve for any analyzer determined from the zero and mid-level calibration gases' responses does not predict the actual responses of the low-level and high-level gases within 2 percent of the span value, the calibration of that analyzer shall be considered invalid. Take corrective measures on the measurement system before repeating the calibration error check and proceeding with the test runs.

6.8 Measurement System Response Time. Introduce zero gas at the calibration gas valve into the flow rate measurement system and the tracer gas measurement system until all readings are stable. Then, quickly switch to introduce the mid-level calibration gas at the calibration value until a stable value is obtained. A stable value is equivalent to a change of less than 1 percent of span value for 30 seconds. Record the response time. Repeat the procedure three times. Conduct the response time check for each analyzer separately before its initial use and at least semiannually thereafter.

6.9 Measurement System Drift Checks. Immediately prior to the start of each test run (within 1 hour of the test run start), introduce zero and mid-level calibration gases, one at a time, to each analyzer through the calibration valve. Adjust the analyzers to respond appropriately. Immediately following each test run (within 1 hour of the end of the test run), or if adjustments to the analyzers or measurement systems are required during the test run, reintroduce the zero- and mid-level calibration gases and record the responses, as described above. Make no adjustments to the analyzers or the measurement system until after the drift checks are made.

If the difference between the analyzer responses and the known calibration gas values exceed the specified limits (Sections 4.2 and 4.3), the test run will be considered invalid and shall be repeated following corrections to the measurement system. Alternatively, recalibrate the measurement system and recalculate the measurement data. Report the test run results using both the initial and final calibration data.

6.10 Analytical Balance. Perform a multipoint calibration (at least five points spanning the operational range) of the analytical balance before the first certification test and semiannually, thereafter. Before each certification test, audit the balance by weighing at least one calibration weight (class F) that corresponds to 50 to 150 percent of the weight of one filter. If the scale cannot reproduce the value of the calibration weight to within 0.1 mg, conduct the multipoint calibration before use.

7. Calculations

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

7.1 Nomenclature.

a = Sample flow rate adjustment factor.
BR = dry wood burn rate, kg/hr (lb/hr), from Method 28, Section 6.3.
B_{ws} = Water vapor in the gas stream, proportion by volume.
c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dsm ^{3} (g/dscf).
E = Particulate emission rate, g/hr.
ΔH = Average pressure differential across the orifice meter (see Figure 5H–1), mm H_2O (in. H_2O).
L_a = Maximum acceptable leakage rate for either a post-test leak check or for a leak-check following a component change; equal to 0.00057 m ^{3}/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.
L_i = Individual leakage rate observed during the leak-check conducted before a component change, m ^{3}/min (cfm).
L_p = Leakage rate observed during the post-test leak-check, m ^{3}/min (cfm).
m_n = Total amount of particulate matter collected, mg.
m_a = Mass of residue of solvent after evaporation, mg.
N_C = Gram atoms of carbon/gram of dry fuel (lb/lb), equal to 0.0425.
N_T = Total dry moles of exhaust gas/Kg of dry wood burned, g-moles/kg (lb-moles/lb).
PR = Percent of proportional sampling rate.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
Q_{sd} = Total gas flow rate, dsm ^{3}/hr (dscf/hr).
Q_T = Flow of tracer gas, liters/min.
S_i = Concentration measured at the SO_2 analyzer for the "ith" 10 minute interval, ppm.
S_1 = Concentration measured at the SO_2 analyzer for the first 10-minute interval, ppm.
T_1 = Absolute average stack gas temperature for the first 10-minute interval, °K (°R).
T_i = Absolute average stack gas temperature at the "ith" 10-minute interval, °K (°R).
T_m = Absolute average dry gas meter temperature (see Figure 5H–3), °K (°R).
T_{std} = Standard absolute temperature, 293 °K (528 °R).
V_a = volume of solvent blank, ml.
V_{aw} = Volume of solvent used in wash, ml.
V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 5H–4), ml.
V_m = Volume of gas sample as measured by dry gas meter, dm ^{3} (dcf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dsm ^{3} (dscf).
$V_{m1(std)}$ = Volume of gas sample measured by the dry gas meter during the first 10-minute interval, corrected to standard conditions, dsm ^{3} (dscf).
$V_{mi(std)}$ = Volume of gas sample measured by the dry gas meter during the "ith" 10-minute interval, dsm ^{3} (dscf).

$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, sm^3 (scf).
W_a = Weight of residue in solvent wash, mg.
Y = Dry gas meter calibration factor.
Y_{CO} = Measured mole fraction of CO (dry), average from Section 5.2.2.2, g/g-mole (lb/lb-mole).
Y_{CO_2} = Measured mole fraction of CO_2 (dry), average from Section 5.2.2.2, g/g-mole (lb/lb-mole).
Y_{HC} = Assumed mole fraction of HC (dry), g/g-mole (lb/lb-mole):
= 0.0088 for catalytic wood heaters;
= 0.0132 for non-catalytic wood heaters;
= 0.0080 for pellet-fired wood heaters.
10 = Length of first sampling period, minutes.
13.6 = Specific gravity of mercury.
100 = Conversion to percent.
θ = Total sampling time, min
θ_1 = Sampling time interval, from the beginning of a run until the first component change, min.

7.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 5H–3).

7.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20 °C, 760 mm Hg or 68 °F, 29.92 in. Hg) by using Equation 5H–1.

$$V_{m(std)} = V_m Y \frac{T_{std}}{T_m}\left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right) = K_1 V_m Y\left(\frac{P_{bar} + (\Delta H/13.6)}{T_m}\right) \quad \text{Eq. 5H-1}$$

where:
K_1 = 0.3858 °K/mm Hg for metric units.
= 17.64 °R/in. Hg for English units.

Note: Equation 5H–1 can be used as written unless the leakage rate observed during any of the mandatory leak-checks (i.e., the post-test leak-check or leak-check conducted before a component change) exceeds L_a.

If L_p exceeds L_a, Equation 5H–1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 5H–1 with the expression:
$[V_m - (L_p - L_a)\theta]$

(b) Case II. One component change made during the sampling run. In this case, replace V_m in Equation 5H–1 by the expression:
$V_m - (L_1 - L_a)\theta_1$
and substitute only for those leakage rates (L_1 or L_p) which exceed L_a.

7.4 Volume of Water Vapor.

$V_{w(std)} = K_2 V_{lc}$ Eq. 5H–2

where:
K_2 = 0.001333 m^3/ml for metric units
= 0.04707 ft^3/ml for English units.

7.5 Moisture Content.

$$B_{ws} = \left(\frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}\right)$$

Eq. 5H-3

7.6 Solvent Wash Blank.

$$W_a = \left(\frac{m_a V_{aw}}{V_a}\right) \quad \text{Eq. 5H-4}$$

7.7 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1, 2, 3, and 4 less the appropriate solvent blanks (see Figure 5H–4).

Note: Refer to Method 5, Section 4.1.5 to assist in calculation of results involving two filter assemblies.

7.8 Particulate Concentration.

$c_s = (0.001 \text{ g/mg})(m_n/V_{m(std)})$
Eq. 5H–5

7.9 Sample Flow Rate Adjustment.

$$a = \frac{S_i}{S_t} \quad \text{Eq. 5H-6}$$

7.10 Carbon Balance for Total Moles of Exhaust Gas (dry)/Kg of Wood Burned in the Exhaust Gas.

$$N_T = \left(\frac{K_3 N_C}{(Y_{CO_2} + Y_{CO} + Y_{HC})}\right)$$

Eq. 5H-7

where:
K_3 = 1000 g/kg for metric units.
K_3 = 1.0 lb/lb for English units.

Note: The NO_x/SO_x portion of the gas is assumed to be negligible.

7.11 Total Stack Gas Flow Rate

$Q_{sd} = K_4 N_T BR$ Eq. 5H–8

where:
K_4 = 0.02406 for metric units, dsm^3/g-mole.
= 384.8 for English units, dscf/lb-mole.

7.12 Particulate Emission Rate.

$E = c_s Q_{sd}$ Eq. 5H–9

7.13 Proportional Rate Variation. Calculate PR for each 10-minute interval, i, of the test run.

$$PR = \left(\frac{\theta S_i \quad V_{mi(std)}}{10 \sum_{i=1}^{n} [S_i \quad V_{mi(std)}]}\right) \times 100 \quad \text{Eq. 5H-10}$$

7.14 Acceptable Results. If no more than 15 percent of the PR values for all the intervals exceed 90 percent < PR < 110 percent, and if no PR value for any interval exceeds 75 < PR < 125 percent, the results are acceptable. If the PR values for the test runs are judged to be unacceptable, report the test run emission results, but do not include the test run results in calculating the weighted average emission rate, and repeat the test.

8. Bibliography

1. Same as for Method 5, citations 1 through 11, with the addition of the following:

2. Oregon Department of Environmental Quality Standard Method for Measuring the emissions and efficiencies of Woodstoves, July 8, 1984. Pursuant to Oregon Administrative Rules Chapter 340, Division 21.

3. American Society for Testing Materials Proposed Test Methods for Heating Performance and Emissions of Residential Wood-fired Closed Combustion-Chamber Heating Appliances. E–6 Proposal P 180. August 1986.

BILLING CODE 6560-50-M

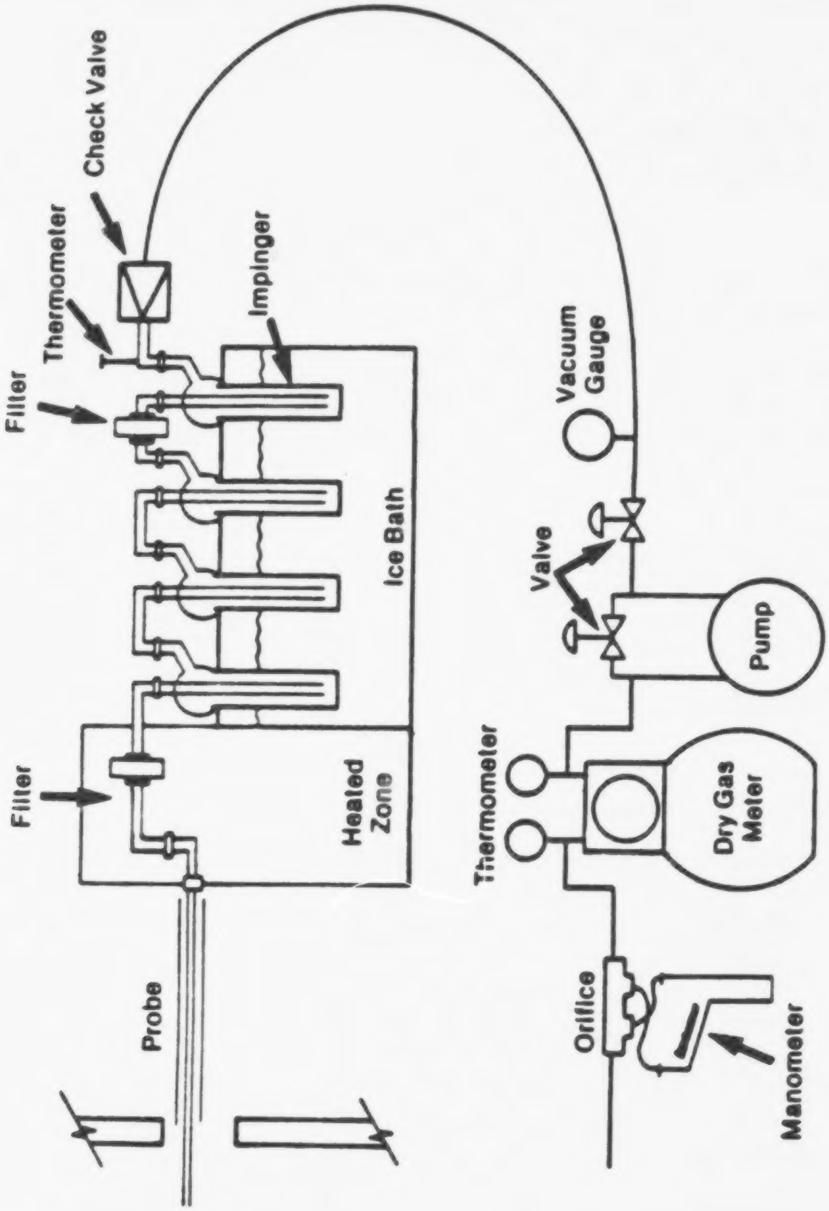

Probe
Heated Zone
Filter
Filter
Thermometer
Check Valve
Impinger
Ice Bath
Vacuum Gauge
Valve
Pump
Dry Gas Meter
Thermometer
Orifice
Manometer

Figure 5H-1. Sampling train.

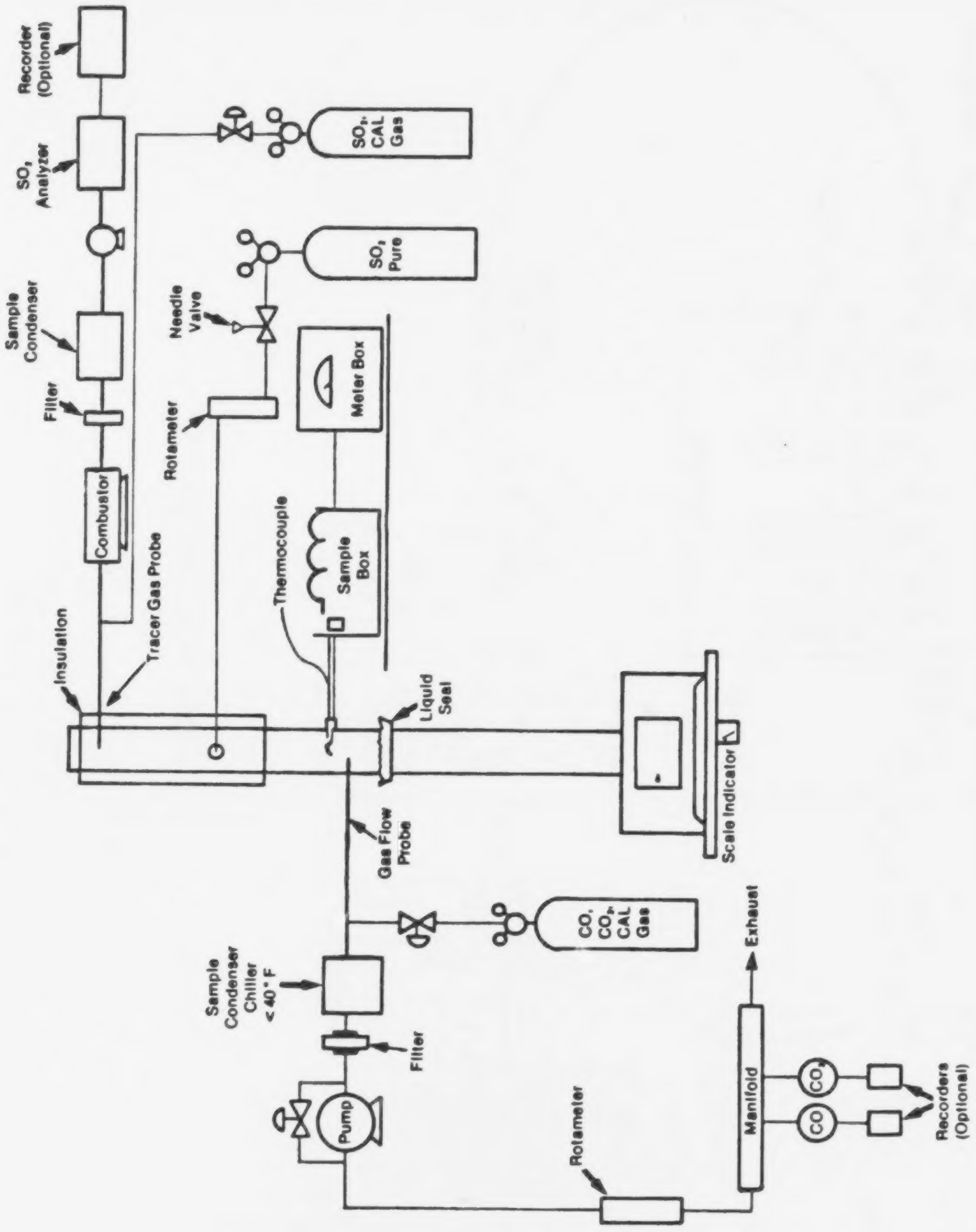

Recorder (Optional)
SO_2 Analyzer
Sample Condenser
Filter
Combustor
Insulation
Tracer Gas Probe
Needle Valve
Rotameter
SO_2 CAL Gas
SO_2 Pure
Meter Box
Thermocouple
Sample Box
Liquid Seal
Scale Indicator
Gas Flow Probe
CO, CO_2, CAL Gas
Sample Condenser Chiller <40° F
Filter
Pump
Rotameter
Manifold
Exhaust
CO
CO_2
Recorders (Optional)

Figure 5H-2. Test system schematic for Method 5H.

Stove
Test Method
Operator
Date
Run No
Start Time
Stop Time
Sample Box No.
Meter Box No
Meter ΔH @ (optional)
C Factor

Pitot tube coefficient, Cp
Room temperature, °C, (°F)
Barometric pressure mb (in. Hg)
Measured or assumed moisture, %
Nozzle identification No. m)
Average calibrated nozzle diameter, mm (in.)
Final leak rate, m³/min, (cfm)
Probe liner material
Draft or static pressure, mm H_2O (in. H_2O)
Filter Nos.

Clock time	Sampling time	Vacuum	Flue temperature	Flow in Flue	Volume sampled in period	Gas sample volume	Gas sample temperature at dry gas meter		Front filter holder temperature	Temperature of gas leaving dryer or last impinger
	(θ) min.	mm Hg (in. Hg)	(T_s) °C (°F)	m³/min (ft³/min)	m³ (ft³)	m³ (ft³)	°C (°F)	°C (°F)	°C (°F)	°C (°F)
Total							Avg	Avg		
Average							Avg			

Figure 5H-3. Data sheet.

Stove
Date
Run No.
Filter Nos.
Amount liquid lost during transport (ml)
Acetone blank volume, ml
Acetone wash volume, ml
Acetone blank concentration, mg/ml
Acetone wash blank, mg

Dichloromethane blank volume, ml
Dichloromethane wash volume, ml
Dichloromethane blank concentration, mg/ml
Dichloromethane wash blank, mg
Water blank volume, ml
Water wash volume, ml
Water blank concentration, mg/ml
Water wash blank, mg

Container number	Weight of particulate collected, mg		
	Final weight	Tare weight	Weight gain
1			
2			
3			
4			
5			
Total			
Less acetone blank			
Less dichloromethane blank			
Less water blank			
Weight of particulate matter			

	Volume of liquid water collected	
	Impinger volume, ml	Silica gel weight, g
Final		
Initial		
Liquid collected		
Total volume collected		g* ml

*Convert weight of water to volume by dividing total weight increase by density of water (1 g/ml).

$$\frac{\text{Increase, g}}{(1\ \text{g/ml})} = \text{Volume water, ml}$$

Figure 5H-4. Analysis data sheet.

BILLING CODE 6560-50-C

Method 28—Certification and Auditing of Wood Heaters

1. Applicability and Principle

1.1 Applicability. This method is applicable for the certification and auditing of wood heaters. This method describes the test facility, test fuel charge, and wood heater operation as well as procedures for determining burn rates and particulate emission rates and for reducing data.

1.2 Principle. Particulate matter emissions are measured from a wood heater burning a prepared test fuel crib in a test facility maintained at a set of prescribed conditions.

2. Definitions

2.1 Burn Rate. The rate at which test fuel is consumed in a wood heater. Measured in kilograms of wood (dry basis) per hour (kg/hr).

2.2 Certification or Audit Test. A series of at least four test runs conducted for certification or audit purposes that meets the burn rate specifications in Section 5.

2.3 Firebox. The chamber in the wood heater in which the test fuel charge is placed and combusted.

2.4 Secondary Air Supply. An air supply that introduces air to the wood heater such that the burn rate is not altered by more than 25 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

2.5 Test Facility. The area in which the wood heater is installed, operated, and sampled for emissions.

2.6 Test Fuel Charge. The collection of test fuel pieces placed in the wood heater at the start of the emission test run.

2.7 Test Fuel Crib. The arrangement of the test fuel charge with the proper spacing requirements between adjacent fuel pieces.

2.8 Test Fuel Loading Density. The weight of the as-fired test fuel charge per unit volume of usable firebox.

2.9 Test Fuel Piece. The 2 x 4 or 4 x 4 wood piece cut to the length required for the test fuel charge and used to construct the test fuel crib.

2.10 Test Run. An individual emission test which encompasses the time required to consume the mass of the test fuel charge.

2.11 Usable Firebox Volume. The volume of the firebox determined using the following definitions:

2.11.1 Height. The vertical distance extending above the loading door, if fuel could reasonably occupy that space, but not more than 2 inches above the top (peak height) of the loading door, to the floor of the firebox (i.e., below a permanent grate) if the grate allows a 1-inch diameter piece of wood to pass through the grate, or, if not, to the top of the grate. Firebox height is not necessarily uniform but must account for variations caused by internal baffles, air channels, or other permanent obstructions.

2.11.2 Length. The longest horizontal fire chamber dimension that is parallel to a wall of the chamber.

2.11.3 Width. The shortest horizontal fire chamber dimension that is parallel to a wall of the chamber.

2.12 Wood Heater. An enclosed, woodburning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

2.13 Pellet Burning Wood Heater. A wood heater which meets the following criteria: (1) The manufacturer makes no reference to burning cord wood in advertising or other literature, (2) the unit is safety listed for pellet fuel only, (3) the unit operating and instruction manual must state that the use of cordwood is prohibited by law, and (4) the unit must be manufactured and sold including the hopper and auger combination as integral parts.

3. Apparatus

3.1 Insulated Solid Pack Chimney. For installation of wood heaters. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. Standard 103 (incorporated by reference. See § 60.17).

3.2 Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.05 kg (0.1 lb) or 1 percent of the initial test fuel charge weight, whichever is greater.

3.3 Wood Heater Temperature Monitors. Seven, each capable of measuring temperature to within 1.5 percent of expected absolute temperatures.

3.4 Test Facility Temperature Monitor. A thermocouple located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1.5 percent of expected temperatures.

3.5 Balance (optional). Balance capable of weighing the test fuel charge to within 0.05 kg (0.1 1b).

3.6 Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 1 percent moisture content.

3.7 Anemometer. Device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

3.8 Barometer. Mercury, aneroid or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg).

3.9 Draft Gauge. Electromanometer or other device for the determination of flue draft or static pressure readable to within 0.50 Pa (0.002 in. H_2O).

3.10 Humidity Gauge. Psychrometer or hygrometer for measuring room humidity.

3.11 Sampling Methods. Use particulate emission measurement Method 5G or Method 5H to determine particulate concentrations, gas flow rates, and particulate emission rates.

4. Test Facility, Test Fuel Properties, and Test Fuel Charge Specifications

4.1 Test Facility.

4.1.1 Wood Heater Flue. Steel flue pipe extending to 2.6±0.15 m (8.5±0.5 ft) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 4.6 + 0.3 m (15±1 ft) above the platform scale, and of the size specified by the wood heater manufacturer. This applies to both freestanding and insert type wood heaters.

Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the wood heater manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance wood heater inserts). Such alternative chimney or flue pipe must remain and be sealed with the wood heater following the certification test.

4.1.2 Test Facility Conditions. The test facility temperature shall be maintained between 18 and 32 °C (65 and 90 °F) during each test run.

Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 1.25 Pa (0.005 in. H_2O) on the wood heater measured when the wood heater is not operating.

For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 1,033 mb (30.5 in. Hg) during any test run.

4.2 Test Fuel Properties. The test fuel shall conform to the following requirements:

4.2.1 Fuel Species. Untreated, air-dried, Douglas fir lumber. Kiln-dried lumber is not permitted. The lumber shall be certified C grade (standard) or better Douglas fir by a lumber grader at the mill of origin as specified in the West Coast Lumber Inspection Bureau standard No. 16 (incorporated by reference. See § 60.17).

4.2.2 Fuel Moisture. The test fuel shall have a moisture content range between 16 to 20 percent on a wet basis (19 to 25 percent dry basis).

Addition of moisture to previously dried wood is not allowed. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

4.2.3 Fuel Temperature. The test fuel shall be at the test facility temperature 18 to 32 °C (65 to 90 °F).

4.3 Test Fuel Charge Specifications.

4.3.1 Fuel Dimensions. The dimensions of each test fuel piece shall conform to the nominal measurements of 2 x 4 and 4 x 4 lumber. Each piece of test fuel (not including spacers) shall be of equal length, except as necessary to meet requirements in Section 6.2.5, and shall closely approximate ⅚ the dimensions of the length of the usable firebox. The fuel piece dimensions shall be determined in relation to the appliance's firebox volume according to guidelines listed below:

4.3.1.1 If the usable firebox volume is less than or equal to 0.043 m^3 (1.5 ft^3), use 2 x 4 lumber.

4.3.1.2 If the usable firebox volume is greater than 0.043 m^3 (1.5 ft^3) and less than or equal to 0.085 m^3 (3.0 ft^3), use 2 x 4 and 4 x 4 lumber. About half the weight of the test fuel charge shall be 2 x 4 lumber, and the remainder shall be 4 x 4 lumber.

4.3.1.3 If the usable firebox volume is greater than 0.085 m^3 (3.0 ft^3), use 4 x 4 lumber.

4.3.2 Test Fuel Spacers. Air-dried, Douglas fir lumber meeting the fuel properties in Section 4.2. The spacers shall be 130 x 40 x 20 mm (5 x 1.5 x 0.75 in.).

4.3.3 Test Fuel Charge Density. The test fuel charge density shall be 112 ± 11.2 kg/m^3 (7 ± 0.7 lb/ft^3) of usable firebox volume on a wet basis.

4.4 Wood Heater Thermal Equilibrium. The average of the wood heater surface temperatures at the end of the test run shall agree with the average surface temperature at the start of the test run to within 70 °C (125 °F).

5. Burn Rate Criteria

5.1 Burn Rate Categories. One emission test run is required in each of the following burn rate categories:

Burn Rate Categories

(Average kg/hr, dry basis)

Category 1	Category 2	Category 3	Category 4
<0.80	0.80 to 1.25	1.25 to 1.90	Maximum burn rate.

5.1.1 Maximum Burn Rate. For Category 4, the wood heater shall be operated with the primary air supply inlet controls fully open (or, if thermostatically controlled, the thermostat shall be set at maximum heat output) during the entire test run, or the maximum burn rate setting specified by the manufacturer's written instructions.

5.1.2 Other Burn Rate Categories. For burn rates in Categories 1 through 3, the wood heater shall be operated with the primary air supply inlet control, or other mechanical control device, set at a predetermined position necessary to obtain the average burn rate required for the category.

5.2 Alternative Burn Rates for Burn Rate Categories 1 and 2. If a wood heater cannot be operated at a burn rate below 0.80 kg/hr, two test runs shall be conducted with burn rates within Category 2. If a wood heater cannot be operated at a burn rate below 1.25 kg/hr, the flue shall be dampered or the air supply otherwise controlled in order to achieve two test runs within Category 2.

Evidence that a wood heater cannot be operated at a burn rate less than 0.80 kg/hr shall include documentation of two or more attempts to operate the wood heater in burn rate Category 1 and fuel combustion has stopped, or results of two or more test runs demonstrating that the burn rates were greater than 0.80 kg/hr when the air supply controls were adjusted to the lowest possible position or settings. Stopped fuel combustion is evidenced when an elapsed time of 30 minutes or more has occurred without a measurable (< 0.05 kg (0.1 lb) or 1.0 percent, whichever is greater) weight change in the test fuel charge. See also Section 6.4.3. Report the evidence and the reasoning used to determine that a test in burn rate Category 1 cannot be achieved; for example, two attempts to operate at a burn rate of 0.4 kg/hr are not sufficient evidence that burn rate Category 1 cannot be achieved.

Note: After July 1, 1990, if a wood heater cannot be operated at a burn rate less than 0.80 kg/hr, at least one test run with an average burn rate of 1.00 kg/hr or less shall be conducted. Additionally, if flue dampering must be used to achieve burn rates below 1.25 kg/hr (or 1.0 kg/hr), results from a test run conducted at burn rates below 0.90 kg/hr need not be reported or included in the test run average provided that such results are replaced with results from a test run meeting the criteria above.

6. Procedures

6.1 Catalytic Combustor and Wood Heater Aging. The catalyst-equipped wood heater or a wood heater of any type shall be aged before the certification test begins. The aging procedure shall be conducted and documented by a testing laboratory accredited according to procedures in § 60.535 of 40 CFR Part 60.

6.1.1 Catalyst-equipped Wood Heater. Operate the catalyst-equipped wood heater using fuel described in Section 4.2 or cordwood with a moisture content between 15 and 25 percent on a wet basis. Operate the wood heater at a medium burn rate (Category 2 or 3) with a new catalytic combustor in place and in operation for at least 50 hours. Record and report hourly catalyst exit temperature data (Section 6.2.2) and the hours of operation.

6.1.2 Non-Catalyst Wood Heater. Operate the wood heater using the fuel described in Section 6.1.1 at a medium burn rate for at least 10 hours. Record and report the hours of operation.

6.2 Pretest Preparation. Record the test fuel charge dimensions and weights, and wood heater and catalyst descriptions as shown in the example in Figure 28–3.

6.2.1 Wood Heater Installation. Assemble the wood heater appliance and parts in conformance with the manufacturer's written installation instructions. Place the wood heater centrally on the platform scale and connect the wood heater to the flue described in Section 4.1.1. Clean the flue with an appropriately sized, wire chimney brush before each certification test.

6.2.2 Wood Heater Temperature Monitors. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of catalyst face area. Record these locations.

Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, on two sidewall surfaces, and on the bottom and back surfaces. Position the monitor sensing tip on the firebox exterior surface inside of any heat shield, air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in both the vertical and horizontal planes passing at right angles through the centroid of the firebox, not including the fuel loading door (total of five temperature monitors).

6.2.3 Test Facility Conditions. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 1 to 2 m (3 to 6 ft) from the front of the wood heater in the 90° sector in front of the wood heater.

Use an anemometer to measure the air velocity. Measure and record the room air velocity before the pretest ignition period (Section 6.3) and once immediately following the test run completion.

Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run.

Measure and record the flue draft or static pressure in the flue at a location no greater than 0.3 m (1 ft) above the flue connector at the wood heater exhaust during the test run at the recording intervals (Section 6.4.2).

6.2.4 Wood Heater Firebox Volume. Determine the firebox volume using the definitions for height, width, and length in Section 2. Volume adjustments due to presence of firebrick and other permanent fixtures may be necessary. Adjust width and length dimensions to extend to the metal wall of the wood heater above the firebrick or permanent obstruction if the firebrick or obstruction extending the length of the side(s) or back wall extends less than one-third of the usable firebox height. Use the width or length dimensions inside the firebrick if the firebrick extends more than one-third of the usable firebox height. If a log retainer or grate is a permanent fixture and the manufacturer recommends that no fuel be placed outside the retainer, the area outside of the retainer is excluded from the firebox volume calculations.

In general, exclude the area above the ash lip if that area is less than 10 percent of the usable firebox volume. Otherwise, take into account consumer loading practices. For instance, if fuel is to be loaded front-to-back an ash lip may be considered usable firebox volume.

Include areas adjacent to and above a baffle (up to two inches above the fuel loading opening) if four inches or more horizontal space exist between the edge of the baffle and a vertical obstruction (e.g., sidewalls or air channels).

6.2.5 Test Fuel Charge. Prepare the test fuel pieces in accordance with the specifications in Section 4.3. Determine the test fuel moisture content with a calibrated electrical resistance meter or other equivalent performance meter. (To convert moisture meter readings from the dry basis to the wet basis: (100)(percent dry reading) ÷ (100 + percent dry reading) = percent moisture wet basis.) Determine fuel moisture for each fuel piece (not including spacers) by averaging at least three moisture meter readings, one from each of three sides, measured parallel to the wood grain. Average all the readings for all the fuel pieces in the test fuel charge. If an electrical resistance type meter is used. penetration of insulated electrodes shall be one-fourth the thickness of the test fuel piece or 19 mm (0.75 in.). whichever is greater. Measure the moisture content within a 4-hour period prior to the test run. Determine the fuel temperature by measuring the temperature of the room where the wood has been stored for at least 24 hours prior to the moisture determination.

Attach the spacers to the test fuel pieces with uncoated. ungalvanized nails or staples as illustrated in Figure 28–1. Attachment of spacers to the top of the test fuel piece(s) on top of the test fuel charge is optional.

To avoid stacking difficulties. or when a whole number of test fuel pieces does not result. all piece lengths shall be adjusted uniformly to remain within the specified loading density. The shape of the test fuel crib shall be geometrically similar to the shape of the firebox volume without resorting to special angular or round cuts on the individual fuel pieces.

6.2.6 Sampling Method. Prepare the sampling equipment as defined by the selected method. Collect one particulate emission sample for each test run.

6.2.7 Secondary Air Adjustment Validation. If design drawings do not show the introductions of secondary air into a chamber outside the firebox (Section 2.4). conduct a separate test of the wood heater's secondary air supply. Operate the wood heater at a burn rate in Category 1 (Sections 5.1 or 5.2) with the secondary air supply operated following the manufacturer's written instructions. Start the secondary air validation test run as described in Section 6.4.1. except no emission sampling is necessary and burn rate data shall be recorded at 5-minute intervals.

After the start of the test run. operate the wood heater with the secondary air supply set as per the manufacturer's instructions. but with no adjustments to this setting. After 25 percent of the test fuel has been consumed. adjust the secondary air supply controls to another setting. as per the manufacturer.s instructions. Record the burn rate data (5-minute intervals) for 20 minutes following the air supply adjustment.

Adjust the air supply control(s) to the original position(s). operate at this condition for at least 20 minutes. and repeat the air supply adjustment procedure above. Repeat the procedure three times at equal intervals over the entire burn period as defined in Section 6.4. If the secondary air adjustment results in a burn rate change of more than an average of 25 percent between the 20-minute periods before and after the secondary adjustments. the secondary air supply shall be considered a primary air supply. and no adjustment to this air supply is allowed during the test run.

6.3 Pretest Ignition. Build a fire in the wood heater in accordance with the manufacturer's written instructions.

6.3.1 Pretest Fuel Charge. Crumpled newspaper loaded with kindling may be used to help ignite the pretest fuel. The pretest fuel. used to sustain the fire. shall meet the same fuel requirements prescribed in Section 4.2. The pretest fuel charge shall consist of whole 2 x 4's that are no less than 1/3 the length of the test fuel pieces. Pieces of 4 x 4 lumber in approximately the same weight ratio as for the test fuel charge may be added to the pretest fuel charge.

6.3.2 Wood Heater Operation and Adjustments. Set the air inlet supply controls at any position that will maintain combustion of the pretest fuel load. At least one hour before the start of the test run. set the air supply controls at the approximate positions necessary to achieve the burn rate desired for the test run. Adjustment of the air supply controls. fuel addition or subtractions. and coalbed raking shall be kept to a minimum but are allowed up to 15 minutes prior to the start of the test run. For the purposes of this method. coalbed raking is the use of a metal tool (poker) to stir coals. break burning fuel into smaller pieces. dislodge fuel pieces from positions of poor combustion. and check for the condition of uniform charcoalization. Record all adjustments made to the air supply controls. adjustments to and additions or subtractions of fuel. and any other changes to wood heater operations that occur during pretest ignition period. Record fuel weight data and wood heater temperature measurements at 10-minute intervals during the hour of the pretest ignition period preceding the start of the test run. During the 15-minute period prior to the start of the test run. the wood heater loading door shall not be open more than a total of 1 minute. Coalbed raking is the only adjustment allowed during this period.

Note: One purpose of the pretest ignition period is to achieve uniform charcoalization of the test fuel bed prior to loading the test fuel charge. Uniform charcoalization is a general condition of the test fuel bed evidenced by an absence of large pieces of burning wood in the coal bed and the remaining fuel pieces being brittle enough to be broken into smaller charcoal pieces with a metal poker. Manipulations to the fuel bed prior to the start of the test run should be done to achieve uniform charcoalization while maintaining the desired burn rate. In addition. some wood heaters (e.g.. high mass units) may require extended pretest burn time and fuel additions to reach an initial average surface temperature sufficient to meet the thermal equilibrium criteria in Section 4.4.

The weight of pretest fuel remaining at the start of the test run is determined as the difference between the weight of the wood heater with the remaining pretest fuel and the tare weight of the cleaned. dry wood heater with or without dry ash or sand added consistent with the manufacturer's instructions and the owner's manual. The tare weight of the wood heater must be determined with the wood heater (and ash. if added) in a dry condition.

6.4 Test Run. Complete a test run in each burn rate category. as follows:

6.4.1 Test Run Start. When the kindling and pretest fuel have been consumed to leave a fuel weight between 20 and 25 percent of the weight of the test fuel charge. record the weight of the fuel remaining and start the test run. Record and report any other criteria. in addition to those specified in this section. used to determine the moment of the test run start (e.g.. firebox or catalyst temperature). whether such criteria are specified by the wood heater manufacturer or the testing laboratory. Record all wood heater individual surface temperatures. catalyst temperatures. any initial sampling method measurement values. and begin the particulate emission sampling. Within 1 minute following the start of the test run. open the wood heater door. load the test fuel charge. and record the test fuel charge weight. Recording of average. rather than individual. surface temperatures is acceptable for tests conducted in accordance with § 60.533(o)(3)(i) of 40 CFR Part 60.

Position the fuel charge so that the spacers are parallel to the floor of the firebox. with the spacer edges abutting each other. If loading difficulties result. some fuel pieces may be placed on edge. If the usable firebox volume is between 0.043 and 0.085 m^3 (1.5 and 3.0 ft^3). alternate the piece sizes in vertical stacking layers to the extent possible. For example. place 2 x 4's on the bottom layer in direct contact with the coal bed and 4 x 4's on the next layer, etc. (See Figure 28–2). Position the fuel pieces parallel to each other and parallel to the longest wall of the firebox to the extent possible within the specifications in Section 6.2.5.

Load the test fuel in appliances having unusual or unconventional firebox design maintaining air space intervals between the test fuel pieces and in conformance with the manufacturer's written instructions. For any appliance that will not accommodate the loading arrangement specified in the paragraph above. the test facility personnel shall contact the Administrator for an alternative loading arrangement.

The wood heater door may remain open and the air supply controls adjusted up to five minutes after the start of the test run in order to make adjustments to the test fuel charge and to ensure ignition of the test fuel charge has occurred. Within the five minutes after the start of the test run. close the wood heater door and adjust the air supply controls to the position determined to produce the desired burn rate. No other adjustments to the air supply controls or the test fuel charge are allowed (except as specified in Sections 6.4.3 and 6.4.4) after the first five minutes of the test run. Record the length of time the wood heater door remains open. the adjustments to the air supply controls. and any other operational adjustments.

6.4.2 Data Recording. Record fuel weight data. wood heater individual surface and catalyst temperature measurements. other wood heater operational data (e.g.. draft). test facility temperature and sampling method data at 10-minute intervals (or more frequently at the option of the tester) as shown on example data sheet. Figure 28–4.

6.4.3 Test Fuel Charge Adjustment. The test fuel charge may be adjusted (i.e.. re-positioned) once during a test run if more than 60 percent of the initial test fuel charge weight has been consumed and more than 10 minutes have elapsed without a measurable (< 0.05 kg (0.1 lb) or 1.0 percent. whichever is greater) weight change. The time used to make this adjustment shall be less than 15 seconds.

6.4.4 Air Supply Adjustment. Secondary air supply controls may be adjusted once during the test run following the manufacturer's written instructions (see Section 6.2.7). No other air supply adjustments are allowed during the test run.

Recording of wood heater flue draft during the test run is optional for tests conducted in accordance with § 60.533(o)(3)(i) of 40 CFR Part 60.

6.4.5 Auxiliary Wood Heater Equipment Operation. Heat exchange blowers sold with the wood heater shall be operated during the test run following the manufacturer's written instructions. If no manufacturer's written instructions are available, operate the heat exchange blower in the "high" position. (Automatically operated blowers shall be operated as designed.) Shaker grates, by-pass controls, or other auxiliary equipment may be adjusted only one time during the test run following the manufacturer's written instructions.

Record all adjustments on a wood heater operational written record.

Note: If the wood heater is sold with a heat exchange blower as an option, test the wood heater with the heat exchange blower operating as described in Sections 5 and 6 and report the results. As an alternative to repeating all test runs without the heat exchange blower operating, the tester may conduct one test run without the blower operating as described in Section 6.4.5 at a burn rate in Category 2 (Section 5.1). If the emission rate resulting from this test run without the blower operating is equal to or less than the emission rate plus 1.0 g/hr for the test run in burn rate Category 2 with the blower operating, the wood heater may be considered to have the same average emission rate with or without the blower operating. Additional test runs without the blower operating are unnecessary.

6.5 Consecutive Test Runs. Test runs on a wood heater may be conducted consecutively provided that a minimum one-hour interval occurs between test runs.

6.6 Additional Test Runs. The testing laboratory may conduct more than one test run in each of the burn rate categories specified in Section 5.1. If more than one test run is conducted at a specified burn rate, the results from at least two-thirds of the test runs in that burn rate category shall be used in calculating the weighted average emission rate (see Section 8.1). The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the weighted average emission rate (see Note: in Section 5.2).

6.7 Pellet Burning Heaters. Certification testing procedures for pellet burning wood heaters are based on the procedures in this method. The differences in the procedures from the sections in Method 28 are as follows:

6.7.1 Test Fuel Properties. The test fuel shall be all wood pellets with a moisture content no greater than 20 percent on a wet basis (25 percent on a dry basis). Determine the wood moisture content with either ASTM-D2016-74(82)(Method A) or ASTM D4442-84. (incorporated by reference. See Section 60.17).

6.7.2 Test Fuel Charge Specifications. The test fuel charge size shall be as per the manufacturer's written instructions for maintaining the desired burn rate.

6.7.3 Wood Heater Firebox Volume. The firebox volume need not be measured or determined for establishing the test fuel charge size. The firebox dimensions and other heater specifications needed to identify the heater for certification purposes shall be reported.

6.7.4 Heater Installation. Arrange the heater with the fuel supply hopper on the platform scale as described in Section 6.2.1.

6.7.5 Pretest Ignition. Start a fire in the heater as directed by the manufacturer's written instructions, and adjust the heater controls to achieve the desired burn rate. Operate the heater at the desired burn rate for at least 1 hour before the start of the test run.

6.7.6 Sampling Method. Method 5G or 5H shall be used for the certification testing of pellet burners. Prepare the sampling equipment as described in Method 5G or 5H. Collect one particulate emission sample for each test run.

6.7.7 Test Run. Complete a test run in each burn rate category as follows:

6.7.7.1 Test Run Start. When the wood heater has operated for at least 1 hour at the desired burn rate, add fuel to the supply hopper as necessary to complete the test run, record the weight of the fuel in the supply hopper (the wood heater weight), and start the test run. Add no additional fuel to the hopper during the test run.

Record all the wood heater surface temperatures, the initial sampling method measurement values, the time at the start of the test, and begin the emission sampling. Make no adjustments to the wood heater air supply or wood supply rate during the test run.

6.7.7.2 Data Recording. Record the fuel (wood heater) weight data, wood heater temperature and operational data, and emission sampling data as described in Section 6.4.2.

6.7.7.3 Test Run Completion. Continue emission sampling and wood heater operation for 2 hours. At the end of the test run, stop the particulate sampling, and record the final fuel weight, the run time, and all final measurement values.

6.7.8 Calculations. Determine the burn rate using the difference between the initial and final fuel (wood heater) weights and the procedures described in Section 8.3. Complete the other calculations as described in Section 8.

7. Calibrations

7.1 Platform Scale. Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to 20 percent to 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.05 kg (0.1 lbs) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

7.2 Balance (optional). Calibrate as described in Section 7.1.

7.3 Temperature Monitor. Calibrate as in Method 2, Section 4.3, before the first certification test and semiannually thereafter.

7.4 Moisture Meter. Calibrate as per the manufacturer's instructions before each certification test.

7.5 Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and semiannually thereafter.

7.6 Barometer. Calibrate against a mercury barometer before the first certification test and semiannually thereafter.

7.7 Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration.

7.8 Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

8. Calculations and Reporting

Carry out calculations retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation.

8.1 Weighted Average Emission Rate.

$$E_w = \frac{\sum_{i=1}^{n} (K_i E_i)}{\sum_{i=1}^{n} K_i} \qquad \text{Eq. 28-1}$$

where:

E_w = Weighted average emission rate, g/hr;

E_i = Emission rate for test run, i, from Method 5G or 5H, g/hr;

K_i = Test run weighting factor = $P_{i+1} - P_{i-1}$;

n = Total number of test runs;

P_i = Probability for burn rate during test run, i, obtained from Table 28-1. Use linear interpolation to determine probability values for burn rates between those listed on the table.

Note: P_0 always equals 0, $P_{(n+1)}$ always equals 1, P_1 corresponds to the probability of the lowest recorded burn rate, P_2 corresponds to the probability of the next lowest burn rate, etc. An example calculation is shown on Figure 28-5.

8.2 Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures for the start of the test run (Section 6.3.1) and for the test run completion (Section 6.3.6). If the two average temperatures do not agree within 70°C (125°F), report the test run results, but do not include the test run results in the test average. Replace such test run results with results from another test run in the same burn rate category.

8.3 Burn Rate.

$$BR = \frac{60\ W_{wd}}{\theta}\ \frac{100\%M_w}{100} \qquad \text{Eq. 28-2}$$

Where:

BR = Dry wood burn rate, kg/hr (lb/hr)
W_{wd} = Total mass of wood burned during the test run, kg (lb)
θ - Total time of test run, min.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent.

8.4 Reporting Criteria. Submit both raw and reduced test data for wood heater tests. Specific reporting requirements are as follows:

8.4.1 Wood Heater Identification. Report wood heater identification information. An example data form is shown on Figure 28-4.

8.4.2 Test Facility Information. Report test facility temperature, air velocity, and humidity information. An example data form is shown on Figure 28-4.

8.4.3 Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

8.4.4 Pretest Procedure Description. Report all pretest procedures including pretest fuel weight, burn rates, wood heater temperatures, and air supply settings. An example data form is shown on Figure 28-4.

8.4.5 Particulate Emission Data. Report a summary of test results for all test runs and the weighted average emission rate. Submit copies of all data sheets and other records collected during the testing. Submit examples of all calculations.

8.4.6 Suggested Test Report Format.

a. Introduction

1. Purpose of test—certification, audit, efficiency, research and development.
2. Wood heater identification—manufacturer, model number, catalytic/noncatalytic, options.
3. Laboratory—name, location (altitude), participants.
4. Test information—date wood heater received, date of tests, sampling methods used, number of test runs.

b. Summary and Discussion of Results

1. Table of results (in order of increasing burn rate)—test run number, burn rate, particulate emission rate, efficiency (if determined), averages (indicate which test runs are used).
2. Summary of other data—test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights, run times.
3. Discussion—Burn rate categories achieved, test run result selection, specific test run problems and solutions.

c. Process Description

1. Wood heater dimensions—volume, height, width, lengths (or other linear dimensions), weight, volume adjustments.
2. Firebox configuration—air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and bypass location and operation (include line drawings or photographs).
3. Process operation during test—air supply settings and adjustments, fuel bed adjustments, draft.
4. Test fuel—test fuel properties (moisture and temperature), test fuel crib description (include line drawing or photograph), test fuel charge density.

d. Sampling Locations

Describe sampling location relative to wood heater. Include drawing or photograph.

e. Sampling and Analytical Procedures

1. Sampling methods—brief reference to operational and sampling procedures and optional and alternative procedures used.
2. Analytical methods—brief description of sample recovery and analysis procedures.

f. Quality Control and Assurance Procedures and Results

1. Calibration procedures and results—certification procedures, sampling and analysis procedures.
2. Test method quality control procedures—leak-checks, volume meter checks, stratification (velocity) checks, proportionality results.

Appendices

1. Results and Example Calculations. Complete summary tables and accompanying examples of all calculations.
2. Raw Data. Copies of all uncorrected data sheets for sampling measurements, temperature records and sample recovery data. Copies of all pretest burn rate and wood heater temperature data.
3. Sampling and Analytical Procedures. Detailed description of procedures followed by laboratory personnel in conducting the certification test, emphasizing particularly parts of the procedures differing from the methods (e.g., approved alternatives).
4. Calibration Results. Summary of all calibrations, checks, and audits pertinent to certification test results with dates.
5. Participants. Test personnel, manufacturer representatives, and regulatory observers.
6. Sampling And Operation Records. Copies of uncorrected records of activities not included on raw data sheets (e.g., wood heater door open times and durations).
7. Additional Information. Wood heater manufacturer's written instructions for operation during the certification test.

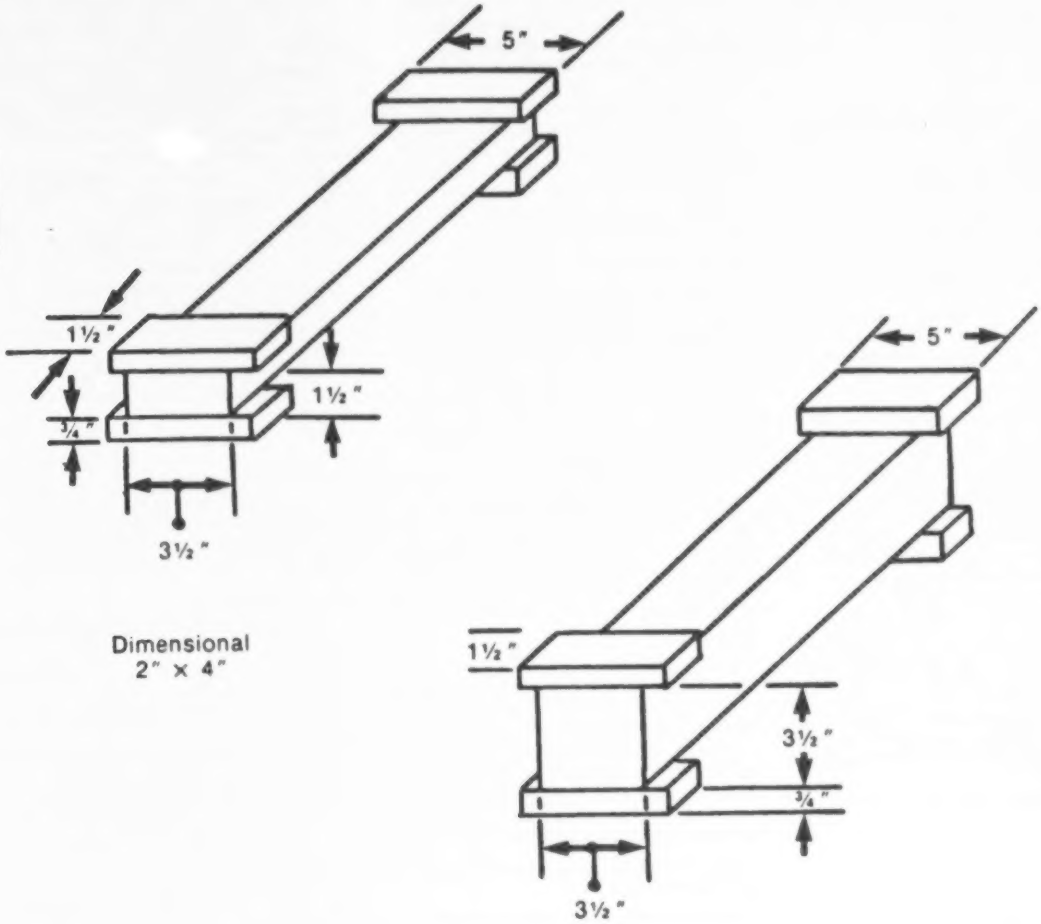
9. Bibliography

1. Oregon Department of Environmental Quality Standard Method for Measuring the Emissions and Efficiencies of Woodstoves, June 8, 1984. Pursuant to Oregon Administrative Rules Chapter 340, Division 21.

2. American Society for Testing Materials. Proposed Test Methods for Heating Performance and Emissions of Residential Wood-Fired Closed Combustion-Chamber Heating Appliances. E-6 Proposal P 180. August, 1986.

3. Radian Corporation. OMNI Environmental Services, Inc., Cumulative Probability for a Given Burn Rate Based on Data Generated in the CONEG and BPA Studies. Package of materials submitted to the Fifth Session of the Regulatory Negotiation Committee, July 16-17, 1986.

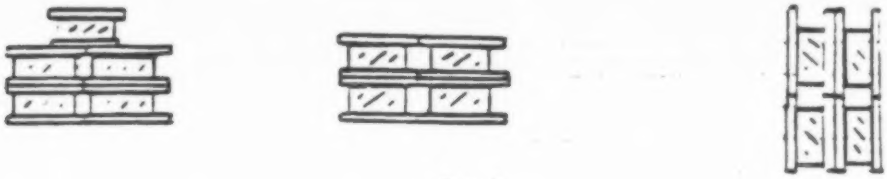
BILLING CODE 6560-50-M


5"
1½"
1½"
¾"
3½"
5"
1½"
3½"
¾"
3½"

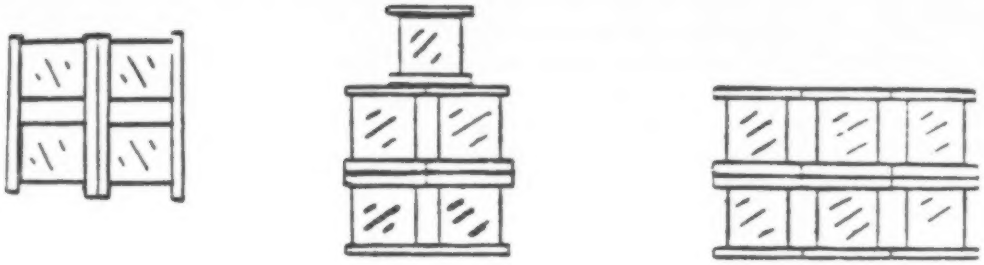
Dimensional
2" × 4"

Dimensional
4" × 4"

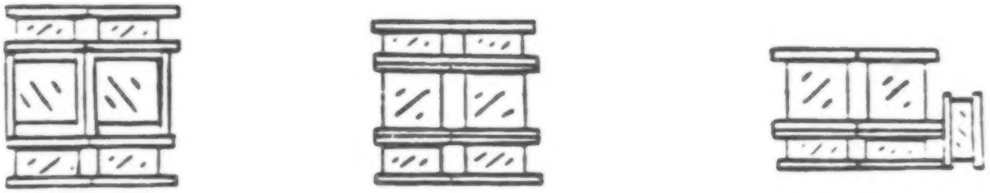
Figure 28-1. Test fuel spacer dimensions.



2 × 4



4 × 4



2 × 4 and 4 × 4

Figure 28 - 2. Test fuel crib arrangements

Appliance Identification

Appliance Manufacturer ______

Address ______

Agent and phone number ______

Name and Model number ______

Weight ______

Serial number ______

Design : Catalytic ______ Noncatalytic ______

Insert ______ Freestanding ______

Woodheater Description : (Attach figure showing air supplies and firebox configuration)

Materials of construction : ______

______

______

______

Air Introduction System : ______

______

______

______

Combustion Control Mechanisms : ______

______

______

______

Internal Baffles : ______

______

______

Other Features : ______

______

______

Catalyst Specifications

Manufacturer ______

Serial Number ______

Age ______ (Hours)

Dimensions ______ (in.)

Firebox Dimensions :

Volume ______ (ft^3)

Length ______ (in.)

Width ______ (in.)

Height ______ (in.)

Adjustments (Describe) ______ (in.)

Test Fuel Information
(For each Test Run)

Weight of Test Charge ______ (lb)

Number of 2 × 4's ______

Number of 4 × 4's ______

Length of test pieces ______ (in.)

Fuel Grade (Certification) ______

Fuel Moisture Content ______ (%)

Diagram or Photograph of Test Fuel Crib

Figure 28-3. Wood Heater and Test Fuel Information.

Sheet ______ of ______

Date ________________

Operator ________________

Sampling Method ________________

Wood Heater Information

Manufacturer ____________

Model ____________

Primary Air Setting ____________

Secondary Air Setting ________

Thermostat Setting ____________

Other Settings ____________

Test Run Information

Test Run No. ________________________

Burn Rate ________________________

Room Temperature before/after _____/_____

Barometric Pressure before/after _____/_____

Relative Humidity before/after _____/_____

Room Air Velocity before/after _____/_____

Surface Temp Average Pretest _____ end _____

Test Run Time (minutes)	Test Fuel Scale Reading (lb)	Surface Temperature					Catalyst Temperature		Flue Draft (in H_2O)
							Inlet (°F)	Outlet (°F)	
(Pretest Period)									
(Test Run Start)									

8870462R

Figure 28 - 4. Test run wood heater operation data sheet

BILLING CODE 6560-50-C

FIGURE 28-5.—EXAMPLE CALCULATION OF WEIGHTED AVERAGE EMISSION RATE

Burn rate category	Test number	Burn rate (Dry-kg/hr)	Emissions (g/hr)
1	1	0.65	5.0
2[1]	2	0.85	6.7
2	3	0.90	4.7
2	4	1.00	5.3
3	5	1.45	3.8
4	6	2.00	5.1

[1] As permitted in Section 6.6, this test run may be omitted from the calculation of the weighted average emission rate because three runs were conducted for this burn rate category.

Test number	Burn rate	P_i	E_i	K_i
1	0.65	0.121	5.0	0.300
2	0.90	0.300	4.7	0.259
3	1.00	0.380	5.3	0.422
4	1.45	0.722	3.8	0.532
5	2.00	0.912	5.1	0.278

$K_1 = P_2 - P_0 = 0.300 - 0 = 0.300$
$K_2 = P_3 - P_1 = 0.380 - 0.121 = 0.259$
$K_3 = P_4 - P_2 = 0.722 - 0.300 = 0.422$
$K_4 = P_5 - P_3 = 0.912 - 0.380 = 0.532$
$K_5 = P_6 - P_4 = 1 - 0.722 = 0.278$

$$\sum_{i=1}^{n} K_i = 0.300 + 0.259 + 0.422 + 0.532 + 0.278$$

$$\sum_{i=1}^{n} = 1.791$$

$$E_w = \frac{\sum_{i=1}^{n} (K_i E_i)}{\sum_{i=1}^{n} K_i}$$

E_w equals (0.3)(5.0) + (0.259)(4.7) + (0.422)(5.3) + (0.532)(3.8) + (0.278)(5.1) divided by 1.791

$E_w = 4.69$ g/hr.

TABLE 28-1.—BURN RATE WEIGHTED PROBABILITIES FOR CALCULATING WEIGHTED AVERAGE EMISSION RATES

Burn rate (kg/hr-dry)	Cumulative Probability (P)
0.00	0.000
0.05	0.002
0.10	0.007
0.15	0.012
0.20	0.016
0.25	0.021
0.30	0.028
0.35	0.033
0.40	0.041
0.45	0.054
0.50	0.065
0.55	0.086
0.60	0.100
0.65	0.121
0.70	0.150
0.75	0.185
0.80	0.220
0.85	0.254
0.90	0.300
0.95	0.328
1.00	0.380
1.05	0.407
1.10	0.460
1.15	0.490
1.20	0.550
1.25	0.572
1.30	0.620
1.35	0.654
1.40	0.695
1.45	0.722
1.50	0.750
1.55	0.779
1.60	0.800
1.65	0.825
1.70	0.840
1.75	0.857
1.80	0.875
1.85	0.882
1.90	0.895
1.95	0.906
2.00	0.912
2.05	0.920
2.10	0.925
2.15	0.932
2.20	0.936
2.25	0.940
2.30	0.945
2.35	0.951
2.40	0.956

TABLE 28-1.—BURN RATE WEIGHTED PROBABILITIES FOR CALCULATING WEIGHTED AVERAGE EMISSION RATES—Continued

Burn rate (kg/hr-dry)	Cumulative Probability (P)
2.45	0.959
2.50	0.964
2.55	0.968
2.60	0.972
2.65	0.975
2.70	0.977
2.75	0.979
2.80	0.980
2.85	0.981
2.90	0.982
2.95	0.984
3.00	0.984
3.05	0.985
3.10	0.986
3.15	0.987
3.20	0.987
3.25	0.988
3.30	0.988
3.35	0.989
3.40	0.989
3.45	0.969
3.50	0.990
3.55	0.991
3.60	0.991
3.65	0.992
3.70	0.992
3.75	0.992
3.80	0.993
3.85	0.994
3.90	0.994
3.95	0.994
4.00	0.994
4.05	0.995
4.10	0.995
4.15	0.995
4.20	0.995
4.25	0.995
4.30	0.996
4.35	0.996
4.40	0.996
4.45	0.996
4.50	0.996
4.55	0.996
4.60	0.996
4.65	0.996
4.70	0.996
4.75	0.997
4.80	0.997
4.85	0.997
4.90	0.997
4.95	0.997
≥5.00	1.000

11.0 REFERENCES

1. Alberty, R. A. and F. Daniels. Physical Chemistry. New York, John Wiley and Sons, Inc. 1967. p. 125.

2. American Society for Testing and Materials. Standard Test Methods for Use and Calibration of Hand-held Moisture Meters. Designation: D4444-84. Philadelphia, Pennsylvania. 1984.

3. American Society for Testing and Materials. Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-base Materials. Designation: D4442-84. Philadelphia, Pennsylvania. 1984.

4. American Society for Testing and Materials. Standard Test Methods for Moisture Content of Wood. Designation: D2016-74. 1983.

5. American Society of Mechanical Engineers. Flue and Exhaust Gas Analyses. Power Test Code (PTC) 19.10-1968. New York, New York. 1968.

6. Quality Assurance Handbook for Air Pollution Measurement Systems. Volume III, Stationary Sources Specific Methods. EPA-600/4-77-027b. U. S. Environmental Protection Agency. Research Triangle Park, North Carolina. 1977.

7. Smith, F., D. E. Wagoner, and R. P. Donovan. Guidelines for Development of a Quality Assurance Program. Volume VII, Determination of CO Emissions from Stationary Sources by NDIR Spectrometry. EPA-650/4-74-005h. U. S. Environmental Protection Agency. Research Triangle Park, North Carolina. 1975.

8. Thomas Register of American Manufacturers and Thomas Register Catalog File. New York, New York. Thomas Publishing Company. 1985.

9. Underwriters Laboratories, Inc. UL103: Standard for Chimneys, Factory-built Residential Type, and Building Heating Appliance. Chicago, Illinois. 1986.

12.0 DATA SHEETS

Blank data sheets are provided in the following pages for the convenience of the user of this Manual to aid in calculations, record keeping, and data reporting. Use of these sheets will help ensure that all the calculations are done correctly and that the reporting of the test data is done correctly. It is suggested that the sheets be removed for duplication and then the originals returned to this manual for future reference. For discussion of the procedures for using the sheets, the reader is referred to the previous sections where example calculations or example applications are provided. An identification number is given before the sheet title (e.g., Sheet 28A-1.1 - Procurement Log indicates that the sheet is used in Figure 1.1 in Section 1.0 of the Method 28A Quality Assurance Procedures).

Sheet	Title
1.1	Procurement Log
1.7	Example Rotameter Calibration Curve
2.1	Scale Calibration Record Sheet
2.2	Temperature Monitor Calibration Record Sheet
2.3	Semiannual Calibration Record Sheet
2.4	Moisture Meter Calibration Sheet
2.5	$\bar{X}$ and R Chart
2.6	Rotameter Calibration Data Sheet
2.7	Rotameter Calibration Curve
2.9	Sample Calibration Curve
2.10	Calibration Drift Verification Record Chart
3.5	Documentation of Test Fuel Measurements
3.8	Measurement of Test Facility Conditions
3.9	Summary of Adjustments and Activities During Pretest Burn Procedures
3.11	Checklist for Method 28A Pretest Procedures
4.1	Test Measurements Recording Sheet
5.1	Orsat Analyzer Gas Analysis Sheet
8.1	Checklist to be Used by Auditors

Item Description	Quantity	Purchase Order Number	Vendor	Date		Cost	Dispo-sition	Comments
				Ordered	Received			

Figure 12.1. Sheet 28A-1.1 - Procurement Log

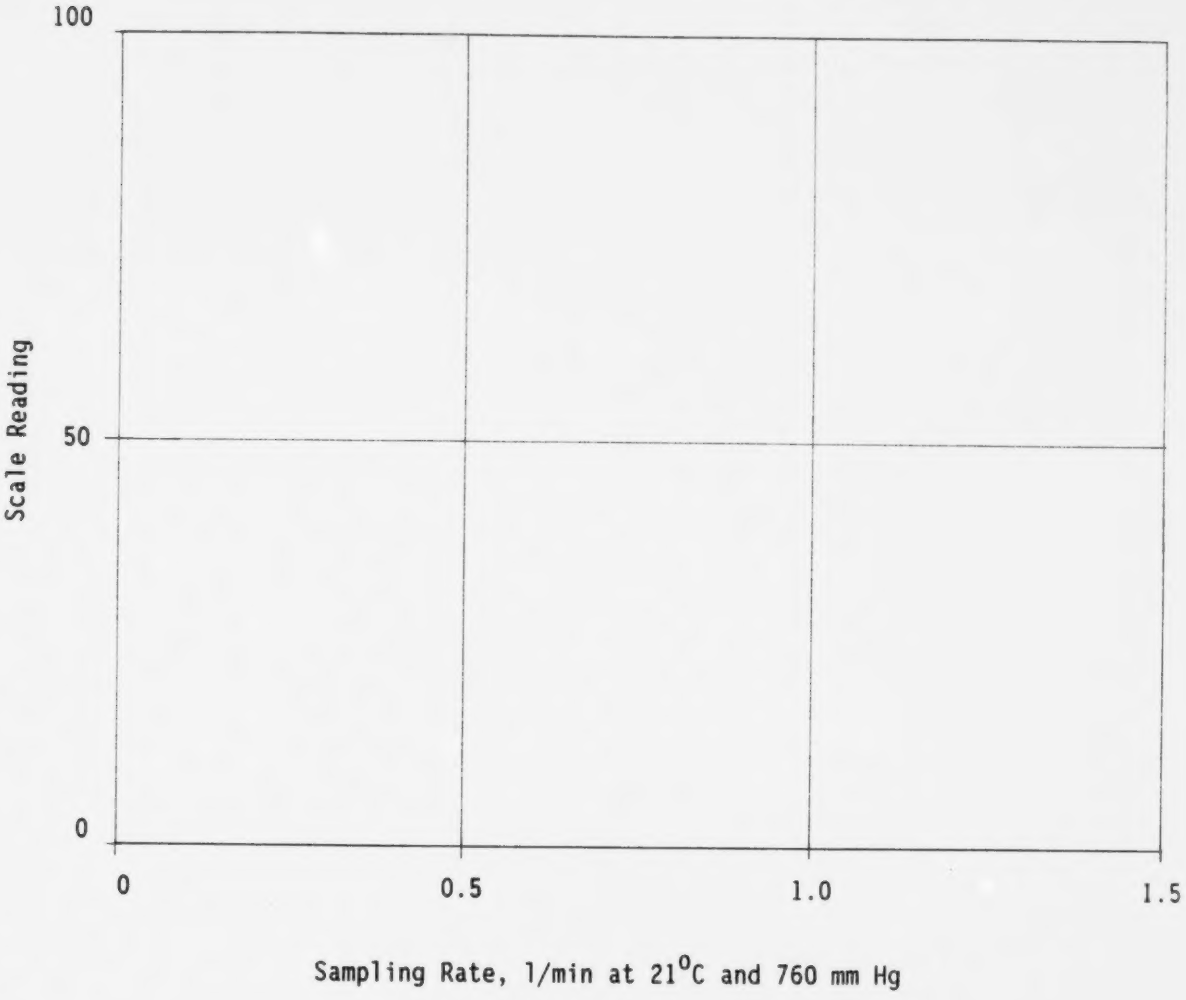


Figure 12.2. Sheet 28A-1.7 - Example Rotameter Calibration Curve

Scale Model: Platform ______________ Capacity ______________ Test Facility ______________

Balance ______________ Resolution ______________ Date ______________

Date	Wood Heater	Platform Temperature	Class F Calibration Weight (A)	Initial Scale Reading or Tare (B)	Final Scale Reading (C)	Measured Calibration Weight (D = C - B)	Difference (D minus A)	Action Taken	Calibrated By

Figure 12.3. Sheet 28A-2.1 - Scale Calibration Record Sheet

Temperature Monitor Type ____________
Identification Number ____________
Readout Device ____________

Test Facility ____________
Reference Temperature Monitor ____________
Identification Number ____________

Date	Temperature Reference Point Source[1]	Observed Temperature		Difference[3] (% R or K)	Action Taken	Calibrated By
		Reference: Fixed Point[2] or Reference Monitor (A)	Measured: Temperature Monitor Reading (B)			

[1] Reference points include ice bath, boiling water, furnace, etc.

[2] Boiling point H_2O in °C = 100 - .94 (29.92 - barometric pressure in in. Hg).
Boiling point H_2O in °F = 212 - 1.69 (29.92 - barometric pressure in in. Hg).

[3] Difference in %K = (A - B) / (A + 273) x 100 for A and B in °C; %R = (A - B) / (A + 460) x 100, for A and B in °F

Figure 12.4. Sheet 28A-2.2 - Temperature Monitor Calibration Record Sheet

Instrument to be Calibrated ____________
Model Number ____________

Test Facility ____________
Calibration Performed By ____________

Date	Method of Measurement	Reference Value (A)	Measured Value (B)	Difference (A minus B)	Acceptable Tolerance	Action Taken

Figure 12.5. Sheet 28A-2.3 - Semiannual Calibration Record Sheet

Moisture Meter Type ____________________

Model Name ____________________

Model Number ____________________

Operating Temperature ____________________

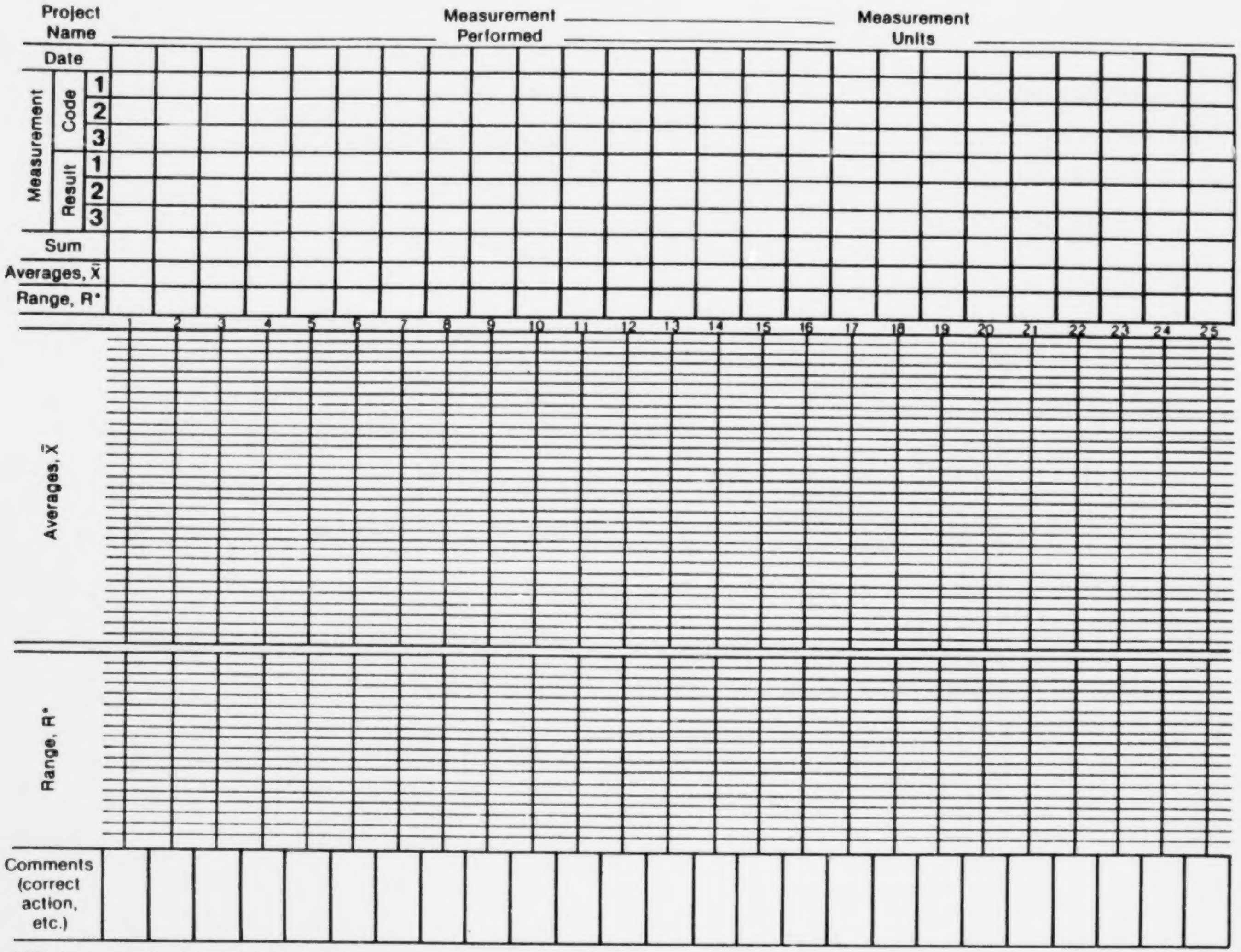
Test Facility ____________________

Calibration Performed By ____________________

Date of Calibration ____________________

Reference Source	Moisture Content Equivalent of Reference Source (A)	Moisture Meter Reading (B)	Difference (Should be within 1%) (A minus B)	Action Taken

Figure 12.6. Sheet 28A-2.4 - Moisture Meter Calibration Sheet


Project Name
Measurement Performed
Measurement Units
Date
Measurement
Code
1
2
3
Result
1
2
3
Sum
Averages, $\bar{X}$
Range, R*
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Averages, $\bar{X}$
Range, R*
Comments (correct action, etc.)

* Maximum result minus minimum result

Figure 12.7. Sheet 28A-2.5 - $\bar{X}$ and R Chart

Rotameter Serial Number ____________________

Location ____________________

Barometric Pressure, P_B, ____________________ in. Hg

Wet Test Meter Number ____________________

Date ____________________

Calibrated By ____________________

R_s, ft^3/min	θ, min	t_w, °F	D_m, in. H_2O	V_w, ft^3	V_r, ft^3	Q_s, ft^3/min

R_s = rotameter setting, ft^3/min (e.g., 0.009, 0.018, 0.027)

θ = time of calibration run, min

t_w = temperature of the gas in wet test meter, °F

D_m = pressure drop on the wet test meter, in. H_2O (a negative number if calibrated as in Figure 2.3)

V_w = gas volume passing through wet test meter, ft^3

V_r = gas volume passing through the rotameter corrected to STP, ft^3

Q_s = flow rate through rotameter, corrected to STP, ft^3/min

t_s = standard temperature, 68°F

P_s = standard pressure, 29.92 in. Hg

$$V_r = \frac{V_w (P_B + D_m / 13.6)(t_s + 460)}{(t_w + 460) P_s} = \frac{17.65\ V_w (P_B + D_m / 13.6)}{(t_w + 460)} = \text{ft}^3 \text{ at STP}$$

$$Q_s = \frac{V_r}{\theta} = \text{ft}^3\text{/min at STP}$$

Figure 12.8. Sheet 28A-2.6 - Rotameter Calibration Data Sheet

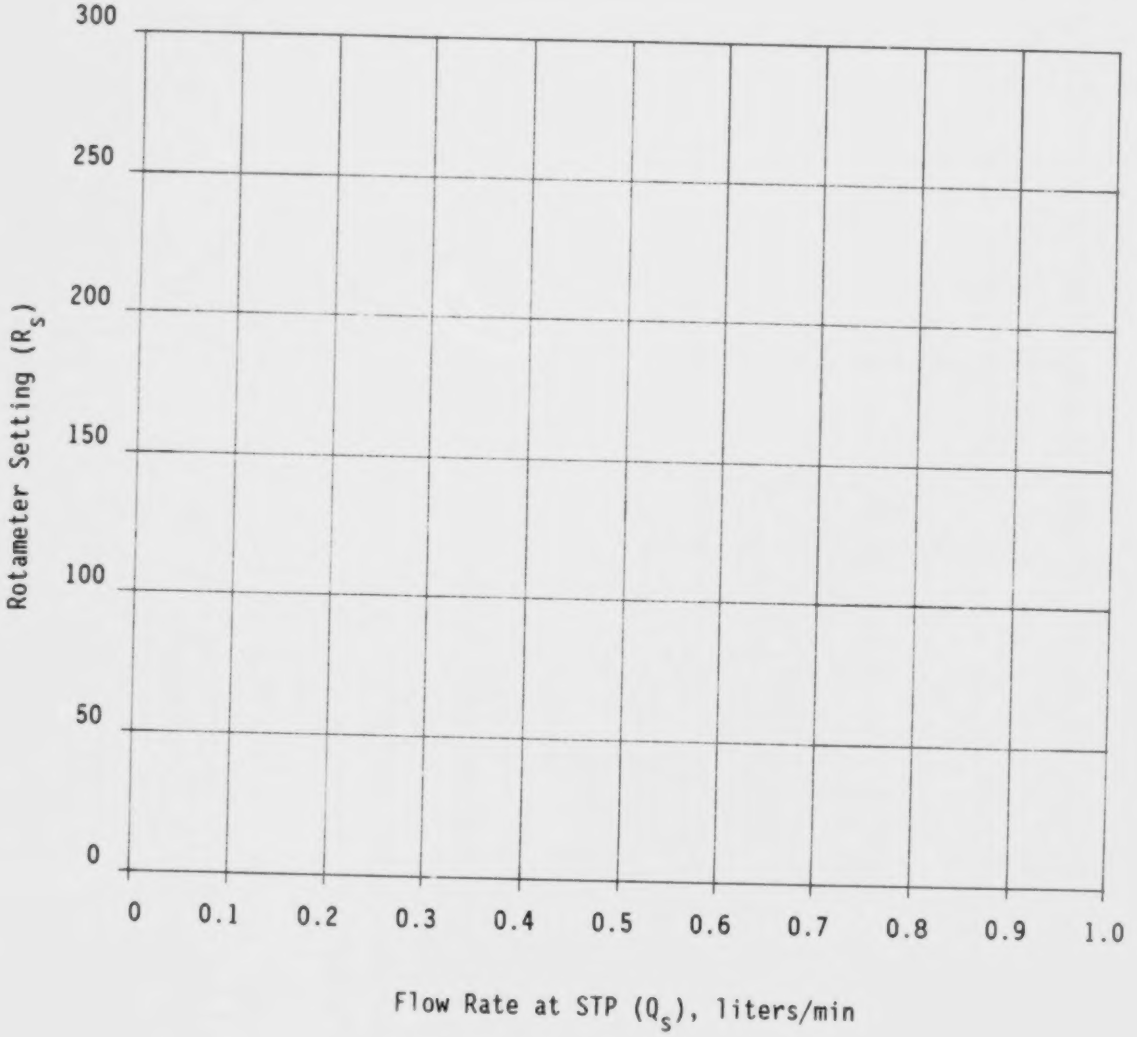


Figure 12.9. Sheet 28A-2.7 - Rotameter Calibration Curve

Location ______________ Date __________ Operator ______________

Analyzer Number ______ Range ______ Flow Rate ______ Cell Pressure ________

Zero Gas ______________ Cylinder Pressure ________ Cylinder Number ________

High-level Gas ________ Cylinder Pressure ________ Cylinder Number ________

Mid-level Gas ________ Cylinder Pressure ________ Cylinder Number ________

Low-level Gas ________ Cylinder Pressure ________ Cylinder Number ________

Zero Control Setting ______________ Span Control Setting ______________

Recorder Type ____________________ Serial Number ____________________

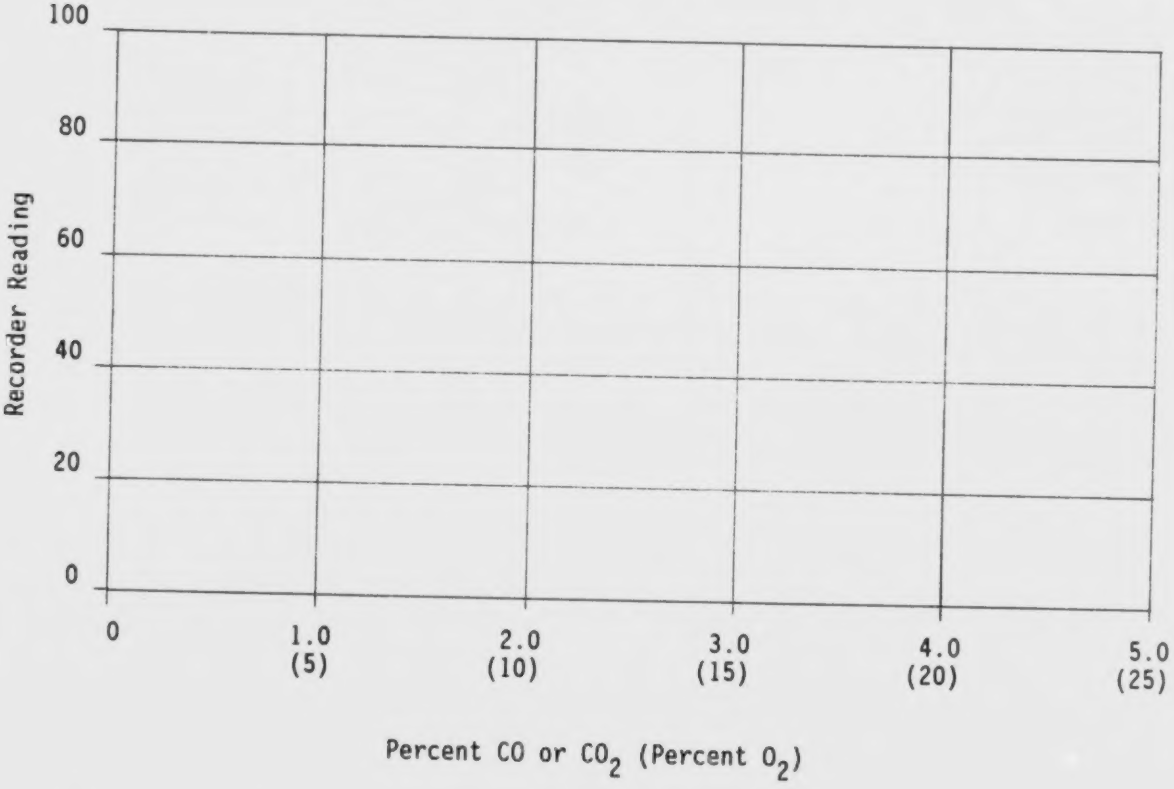


Figure 12.10. Sheet 28A-2.9 - Sample Calibration Curve

Location ______________________

Analyzer ______________________

Operator ______________________

Post-test ________ Pretest ________

Date	Gas	Zero		High- or Mid-range		Percent Difference
		Unadjusted	Adjusted	Unadjusted	Adjusted	

Figure 12.11. Sheet 28A-2.10 - Calibration Drift Verification Record Chart

1.0 Wood Heater Test Fuel Information

Wood Heater Manufacturer ______________
Wood Heater Model ______________
Run Number ______________
Date ______________

2.0 Pretest Fuel Measurements

Piece	Length (inches)	Dimension (e.g. 4 × 4)	Moisture Meter Readings (% Moisture Dry Basis)			Average % Moisture	Corrected Average*
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

* Corrected for Moisture Meter Pin Type and Test Fuel Temperature

Figure 12.12. Sheet 28A-3.5 - Documentation of Test Fuel Measurements

3.0 Test Fuel Measurements

Piece	Length (inches)	Dimension (e.g. 4 × 4)	Moisture Meter Readings (% Moisture Dry Basis)			Average % Moisture	Corrected Average*
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

* Corrected for Moisture Meter Pin Type and Test Fuel Temperature

Test Fuel Temperature ____________
Correction Factor for Pin Type, and Fuel Temperature ____________
Clock Time of Moisture Readings ____________

4.0 Test Fuel Crib

Weight of Test Charge ____________ (lbs)
Number of Spacers ____________
Diagram of Test Fuel Crib

5.0 Conversion to Wet Basis MC

$$\%WB = \frac{100 \times \%DB}{100 + \%DB}$$

%WB = percent moisture content, wet basis

%DB = percent moisture content, dry basis

Figure 12.12. Sheet 28A-3.5 (Continued)

Wood Heater Manufacturer: Date of Test:

Wood Heater Model: Operator:

	Pretest Measurement	Post-Test Measurement
Barometric Pressure (in. Hg)		
Room Temperature (°F)		
Relative Humidity (%)		
Room Air Velocity (ft/min)		
Induced Draft (in. H_2O)		

Remarks:

Figure 12.13. Sheet 28A-3.8 - Measurement of Test Facility Conditions

Operation	Time of Operation	Action Checklist
1. Ignite pretest fuel	After test fuel charge has been prepared and sampling trains are prepared	______
2. Set the air inlet supply controls at any position that will maintain combustion of the pretest fuel	After ignition of the pretest fuel	______
3. Set the air inlet supply controls at the approximate positions necessary to achieve the lowest possible burn rate	At least 1 hour prior to the start of the the test run	______
4. If burn rate is greater than 0.80 kg/m, seal air inlets and close flue damper according to guidelines in Section 3.1.8.2 of this manual.	Some modifications may have to be performed before the pretest burn	______
5. Make any final inlet supply control or fuel adjustments	Up to 15 minutes prior to start of the test run	______
6. Remove pretest fuel if necessary to adjust the coalbed weight and achieve uniform charcoalization	Up to 15 minutes prior to start of the test run	______
7. Rake the coal bed to a uniform height	Allowed any time	______
8. Start test run	When the weight of the remaining pretest fuel is between 20 and 25 percent of the weight of the test fuel charge (and no adjustments, excluding coal bed rakings, were made in the last 15 minutes)	______
9. Begin sampling and record all initial sampling measurement values	Immediately following the start of the test run	______
10. Load test fuel charge and record test fuel charge weight	Within 1 minute of starting the test run	______

Figure 12.14. Sheet 28A-3.9 - Summary of Adjustments and Activities During Pretest Burn Procedures

	Acceptable	
Activity	Yes	No
I. PROCESS OPERATION CHECKS		
Measurement of Firebox Volume		
1. Firebox dimensions measured from actual wood heater to be tested?	____	____
2. Firebox dimensions checked against engineering drawings?	____	____
3. Firebox volume calculated?	____	____
4. Volume determination documented including calculations, illustrations, and volume adjustments?	____	____
5. Volume determination independently calculated and confirmed?	____	____
Wood Heater Installation		
6. Flue pipe cleaned and assembled leak-free?	____	____
7. Flue pipe and solid pack chimney installed to allow unobstructive vertical scale mcvement?	____	____
8. Liquid seal level checked (if applicable)?	____	____

General Comments

Figure 12.15. Sheet 28A-3.11 - Checklist for Method 28A Pretest Procedures

Activity	Acceptable	
	Yes	No
Wood Heater Installation (Continued)		
9. Induced draft measured and adjusted to less than 0.005 in. H_2O?		
10. Flue pipe sampling ports in location above 7.5 ±0.5 ft above platform scale?		
Apparatus Check and Calibrations		
11. Calibration records checked and verified for platform scale?		
12. Calibration records checked and verified for optional fuel balance?		
13. Platform scale single-point calibration checked and acceptable?		
14. Moisture meter calibration performed and recorded?		
15. Calibration records checked and verified for anemometer?		
16. Calibration records checked and verified for barometer?		
17. Calibration records checked and verified for relative humidity gauge?		
General Comments		

Form 28A-3.11. Checklist for Method 28A Pretest Procedures (Continued)

Activity	Acceptable	
	Yes	No
Apparatus Check and Calibrations (Continued)		
18. Calibration records checked and verified for draft gauge?	____	____
19. Calibration records checked and verified for temperature monitors?	____	____
Test Fuel Measurements		
20. Moisture content of each test fuel piece measured?	____	____
21. Moisture readings, fuel temperature, and meter correction factors documented?	____	____
22. Test fuel pieces conform to the grade and dimensional specifications required?	____	____
Test Fuel Crib Construction		
23. Test fuel length approximately 5/6 the length of the firebox?	____	____
24. Length of each test fuel piece documented?	____	____
25. Test fuel crib configuration documented?	____	____
26. Test fuel crib meets weight and nominal size specifications?	____	____

General Comments

Figure 12.15. Sheet 28A-3.11 (Continued)

	Acceptable	
Activity	Yes	No
II. ORSAT INTEGRATED SAMPLING CHECKS		
1. Probe inserted at centroid of flue pipe and sealed?	____	____
2. Filters (in probe or external) replaced?	____	____
3. Vacuum pump leak checked and operating properly?	____	____
4. Condenser cleaned and filled with ice or coolant (if necessary), moisture drain closed?	____	____
5. Flexible bags leak checked?	____	____
6. Rotameters operating properly and calibration records checked?	____	____
7. Orsat analyzer reagent condition checked?	____	____
8. System leak checked?	____	____

General Comments

Figure 12.15. Sheet 28A-3.11 (Continued)

Activity	Acceptable	
	Yes	No
III. CEMS PRETEST CHECKS		
1. Probe inserted at centroid of flue pipe and sealed?	____	____
2. Filters (in probe or external) replaced?	____	____
3. Vacuum pump leak checked and operating properly?	____	____
4. Condenser cleaned and filled with ice or coolant, moisture drain closed?	____	____
5. Rotameters cleaned and calibrated?	____	____
6. Analyzers warmed up >1 hour?	____	____
7. Multipoint calibration performed?	____	____
8. System leak checked?	____	____
9. Sample flow set at same rate used during calibration?	____	____
10. Sample system purged?	____	____

General Comments

Figure 12.15. Sheet 28A-3.11 (Continued)

DATE OF TEST:

OPERATOR:

WOOD HEATER MANUFACTURER:

WOOD HEATER MODEL:

TEST FACILITY:

SHEET NUMBER:

Time (min)	Test Fuel Scale Reading (lb)	Change in Test Fuel Weight (lb)	Concentration			Flow Rate				Room Temp. (°F)	Flue Draft (in. H_2O)	Adjustments/Remarks
			O_2	CO_2	CO	#1	#2	#3	#4			

Figure 12.16. Sheet 28A-4.1 - Test Measurements Recording Sheet

Test Facility Manufacturer ______________________

Wood Heater Model ______________________

Date ______________________

Test Number ______________________

Sampling Time ______________________

Sample Bag Number ______________________

Ambient Temperature ______________________

Operator ______________________

Run	1		2		3		
Gas	Actual Reading	Net	Actual Reading	Net	Actual Reading	Net	Average Net Volume
CO_2							
O_2 (Net is Actual O_2 Reading Minus Actual CO_2 Reading)							
CO (Net is Actual CO Reading Minus Actual O_2 Reading)							

Figure 12.17. Sheet 28A-5.1 - Orsat Analyzer Gas Analysis Sheet

Yes	No	Comment	Operation
			Presampling Preparations
___	___	______	1. Knowledge of process conditions
___	___	______	2. Traceability of calibration gas established
___	___	______	3. Calibration of pertinent equipment
			On-Site Measurements
___	___	______	4. Leak test of sampling train
___	___	______	5. Analyzer warm-up per manufacturer's recommendations (if applicable)
___	___	______	6. Purging the train prior to sampling
___	___	______	7. Constant rate sampling
___	___	______	8. Frequency of zero and span checks
___	___	______	9. Drying agents and filters checked and replaced frequently
			Post-Sampling
___	___	______	10. Transfer and handling of sample (if applicable)
___	___	______	11. Data reduction procedure/check
___	___	______	12. Calibration checks

General Comments

Figure 12.18. Sheet 28A-8.1 - Checklist to be Used by Auditors